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Thyristors, Rectifiers

and Diacs

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Data
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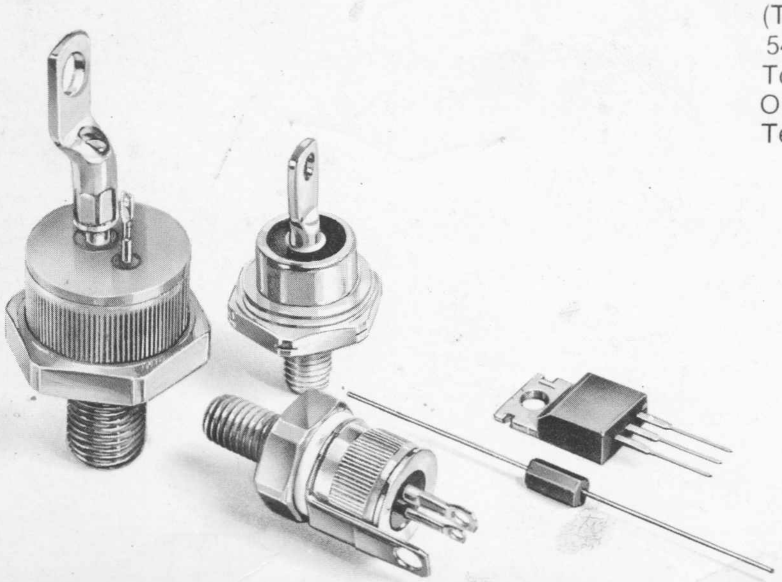

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RCA Solid State
'74 DATABOOK Series

Thyristors, Rectifiers, and Diacs

This DATABOOK contains complete data and related application notes on thyristors, rectifiers, and diacs presently available from RCA Solid State Division as standard products. The new RCA type-numbering system for these devices is explained, and product matrix charts are given on pages 14–24 for ease of type selection. Data sheets are then grouped in the following categories: (a) triacs, (b) silicon controlled rectifiers, (c) rectifiers, (d) diacs. Application notes are included in numerical order following the data sheets.

A feature of this DATABOOK is the complete Guide to RCA Solid State Devices at the back of the book. This section includes a developmental-to-commercial-number cross-reference index, a comprehensive subject index, and a complete index to all standard devices in the solid-state product line: linear integrated circuits, MOS field-effect (MOS/FET) devices, COS/MOS integrated circuits, power transistors, power hybrid circuits, rf power devices, thyristors, rectifiers, and diacs. All listings include references to volume number and page number in the 1974 7-volume DATABOOK series described on the facing page.

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New solid-state devices and related publications announced during the year are described in a monthly newsletter entitled "What's New in Solid State". If you obtained your DATABOOK(s) directly from RCA, your name is already on the mailing list for this newsletter. If you obtained your book(s) from a source other than RCA and wish to receive the newsletter, please fill out the form on page 4, detach it, and mail it to RCA.

Each newsletter issue contains a "bingo"-type fast-response form for your use in requesting information on new devices of interest to you. If you wish to receive all new product information published throughout the year, without having to use the newsletter response form, you may subscribe to a mailing service which will bring you all new data sheets and application notes in a package every other month. You can also obtain a binder for easy filing of all your supplementary material. Provisions for obtaining information on the update mailing service and the binder are included in the order form on page 4.

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Company

Address (Number) (Street, RFD, P.O. Box)

Home ☐
Business ☐ (City) (State or Prov.)

(Country) (Zip or Pstl. Zone)

Function: (Check One)

A ☐ Executive/Administration
B ☐ Purchasing/Procurement
C ☐ Research/Development
D ☐ Design Engineer
E ☐ Application/Components Engineer
F ☐ Production/Manufacturing
G ☐ Documentation/Library
H ☐ Reliability/QA
I ☐ Education/Training
J ☐ Program/Project Management
K ☐ Marketing

Activity: (Check One)

A ☐ Broadcast
B ☐ Communication
C ☐ Instrumentation/Control
D ☐ Computer/Data Processing
E ☐ Computer, Peripheral
F ☐ Automotive
G ☐ Industrial
H ☐ Medical
I ☐ Research
J ☐ Transportation
K ☐ Consumer, Electronic
L ☐ Consumer, Appliance
M ☐ Space
N ☐ Ordnance
O ☐ Avionics
P ☐ Electronic Warfare

Product Interest:
(Indicate order of interest if more than one is marked)

A ☐ Linear IC's
B ☐ Digital IC's, COS/MOS
C ☐ Digital IC's, Bipolar
D ☐ Thyristors/Rectifiers
E ☐ Liquid Crystals
F ☐ Semiconductor Diodes
G ☐ RF Power Semiconductors
H ☐ MOSFETS
I ☐ Power Transistors
J ☐ Power Hybrid Circuits

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New RCA Type-Numbering System

A new system of type numbers has been adopted for all RCA triacs, SCR's, rectifiers, and diacs previously identified by 100-, 40000-, 41000-, 43000-, 44000-, and 45000-series numbers. Type numbers for JEDEC (1N- and 2N-series) devices, which are registered with the Joint Electron Devices Engineering Council of the Electronic Industries Association (EIA), are not affected.

The new type numbers for non-JEDEC RCA thyristors, rectifiers, and diacs consist of an alpha-numeric code that immediately identifies the basic type of device and provides information on significant device features. The basic product type is indicated by the initial letter of the type-number designation; i.e., T = triac, S = SCR, and D = rectifier or diac. The numbers following the initial letter indicate device current ratings, type of package, and electrical variants within a series. The suffix letter(s) define the voltage rating of the device.

Sixteen suffix letters are used to represent specific voltage ratings in the range from 15 to 1000 volts. Combinations of these letters can be used to indicate voltage ratings that differ from the sixteen basic values. (For example, the suffix DF is used for a voltage rating of 450 volts; i.e., D + F = 400 + 50 = 450 volts.)

The charts and matrix shown below provide a detailed explanation of the new type number codes. For convenience of type selection, the "old" numbers are included in the index to devices on pages 8-10, and a cross-reference guide that relates "old" type numbers to the new numbers that replace them is provided on pages 11-12.

Graphic Representation of Rectifier and Diac Numbering System

D I I 0 0 A

- **D** — Indicates Rectifier or Diac
- **I** — Indicates Type: 1 = Standard; 2 = Fast Recovery; 3 = Diac
- **I** — Indicates Package: 1 = DO-1; 2 = DO-15; 3 = TO-1; 4 = DO-4; 5 = DO-5; 6 = DO-26; 7 = DO-26 Insulated
- **00** — Indicates Average Current Rating I_O (00 indicates $I_O < 1$ A)
- **A** — Voltage Designation: Q = 15 V; U = 25 V; Y = 30 V; F = 50 V; A = 100 V; G = 150 V; B = 200 V; H = 250 V; C = 300 V; D = 400 V; E = 500 V; M = 600 V; S = 700 V; N = 800 V; T = 900 V; P = 1000 V; PA = 1100 V; PB = 1200 V

Graphic Representation of Thyristor Numbering System

T 2 3 0 0 A

- **T** — Indicates Type: T = Triac; S = SCR
- **23** — Indicates Broad Generic Classification on basis of I_T(RMS) Rating
- **0** — Identifies Package Variants
- **0** — Identifies Electrical Variants
- **A** — Voltage Designation (as shown at left)

I_T(RMS) Ratings (A)	Standard Devices	Fast-Turnoff Devices
0 - 2.5	00 - 09	10 - 19
2.5 - 8	20 - 29	30 - 39
8 - 15	40 - 49	50 - 59
15 - 40	60 - 69	70 - 79
> 40	80 - 89	90 - 99

(NOTE: The first five digits, e.g., T2300, provide the basic device series designation.)

Thyristor Numbering Matrix

TRIACS

Generic Class	Package Variants	Electrical Variants
T23 : 2.5A sensitive-gate types	0 : TO-5 1 : TO-5 with radiator	0 : I_{GT} = 3 mA 1 : I_{GT} = 4 mA 3 : I_{GT} = 25 mA 4 : I_{GT} = 10 mA; 400-Hz type 5 : I_{GT} = 25 mA; 400-Hz type 6 : I_{GT} = 25 mA; zero-voltage-switch type
T26 : 6-A types	0 : Mod. TO-5 1 : TO-5 with radiator 2 : TO-5 with heat spreader	0 : I_{GT} = 25 mA 1 : I_{GT} = 50 mA; I^+ and III^- modes 4 : I_{GT} = 4.25 mA; 400-Hz type 6 : zero-voltage-switch type
T27 : 6-A types	0 : TO-66 1 : TO-66 with radiator	
T47 : 15-A types	0 : TO-66 1 : TO-66 with radiator	

Thyristor Numbering Matrix
TRIACS (cont'd)

Generic Class	Package Variants	Electrical Variants
T41 : 10-to-15-A types	0 : press fit 1 : stud 2 : isolated stud	0 : I_T(RMS) = 15 A 1 : I_T(RMS) = 10 A 4 : I_T(RMS) = 15 A; 400-Hz type 5 : I_T(RMS) = 10 A; 400-Hz type 6 : I_T(RMS) = 15 A; zero-voltage-switch type 7 : I_T(RMS) = 10 A; zero-voltage-switch type
T25 : 6-A plastic types	0 : VERSAWATT 5 : ISOWATT	0 : I_{GT} = 25 mA 1 : I_{GT} = 80 mA; I^+ and III^- modes 6 : zero-voltage-switch type
T28 : 8-A plastic types	0 : VERSAWATT 5 : ISOWATT	0 : I_{GT} = 25 mA 1 : I_{GT} = 80 mA; I^+ and III^- modes 6 : zero-voltage-switch type
T64 : 30-A and 40-A types	0 : press-fit 1 : stud 2 : isolated stud	0 : I_T(RMS) = 40 A 1 : I_T(RMS) = 30 A 4 : I_T(RMS) = 40 A; 400-Hz type 5 : I_T(RMS) = 25 A; 400-Hz type 6 : I_T(RMS) = 40 A; zero-voltage-switch type 7 : I_T(RMS) = 30 A; zero-voltage-switch type
T84 : 60-A and 80-A types	0 : press-fit, flexible leads 1 : stud, flexible leads 2 : isolated stud, flexible leads 3 : press-fit 4 : stud 5 : isolated stud	0 : I_T(RMS) = 80 A 1 : I_T(RMS) = 60 A

SCR's

Generic Class	Package Variants	Electrical Variants
S20 : 4-A plastic types	6 : VERSAWATT	0 : I_{GT} = 0.2 mA 1 : I_{GT} = 0.5 mA 2 : I_{GT} = 2.0 mA
S22 : 2-A types	0 : TO-8	
S24 : 4.5-A types	0 : TO-8	
S26 : 7-A types	0 : low-profile TO-5 1 : modified TO-5 with radiator 2 : modified TO-5 with heat spreader	
S27 : 5-A types	0 : TO-66 1 : TO-66 with radiator	
S37 : 5-A fast-turn-off types	0 : TO-66 1 : TO-66 with radiator	0 : I_{GT} = 40 mA; V_{GT} = 4 V 1 : I_{GT} = 35 mA 2 : I_{GT} = 45 mA 3 : V_{GT} = 2 V 4 : V_{GT} = 3.5 V 5 : I_{GT} = 30 mA; $V_{(BO)}$ = 500 V 6 : I_{GT} = 30 mA; $V_{(BO)}$ = 400 V
S38 : ITR's	0 : TO-66	
S40 : 12.5-A types	0 : TO-3	
S62 : 10-A and 20-A types	0 : press-fit 1 : stud 2 : isolated stud	0 : I_T(RMS) = 20 A 1 : I_T(RMS) = 10 A
S64 : 16-A, 25-A, and 35-A types	0 : press-fit 1 : stud 2 : isolated stud	0 : I_T(RMS) = 35 A 1 : I_T(RMS) = 25 A 2 : I_T(RMS) = 16 A
S74 : 35-A fast-turn-off types	3 : TO-48	

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RCA Type No.	Former Type No.■	Data Sheet File No.	Page No.	Type of Device	Current (A)	Voltage (V)
1N248C	—	6	287	Rectifier	20	50
1N249C	—	6	287	Rectifier	20	100
1N250C	—	6	287	Rectifier	20	200
1N440B	—	5	252	Rectifier	0.75	100
1N441B	—	5	252	Rectifier	0.75	200
1N442B	—	5	252	Rectifier	0.75	300
1N443B	—	5	252	Rectifier	0.75	400
1N444B	—	5	252	Rectifier	0.75	500
1N445B	—	5	252	Rectifier	0.75	600
1N536	—	3	255	Rectifier	0.75	50
1N537	—	3	255	Rectifier	0.75	100
1N538	—	3	255	Rectifier	0.75	200
1N539	—	3	255	Rectifier	0.75	300
1N540	—	3	255	Rectifier	0.75	400
1N547	—	3	255	Rectifier	0.75	600
1N1095	—	3	255	Rectifier	0.75	500
1N1183A	—	38	291	Rectifier	40	50
1N1184A	—	38	291	Rectifier	40	100
1N1186A	—	38	291	Rectifier	40	200
1N1187A	—	38	291	Rectifier	40	300
1N1188A	—	38	291	Rectifier	40	400
1N1189A	—	38	291	Rectifier	40	500
1N1190A	—	38	291	Rectifier	40	600
1N1195A	—	6	287	Rectifier	20	300
1N1196A	—	6	287	Rectifier	20	400
1N1197A	—	6	287	Rectifier	20	500
1N1198A	—	6	287	Rectifier	20	600
1N1199A	—	20	283	Rectifier	12	50
1N1200A	—	20	283	Rectifier	12	100
1N1202A	—	20	283	Rectifier	12	200
1N1203A	—	20	283	Rectifier	12	300
1N1204A	—	20	283	Rectifier	12	400
1N1205A	—	20	283	Rectifier	12	500
1N1206A	—	20	283	Rectifier	12	600
1N1341B	—	58	281	Rectifier	6	50
1N1342B	—	58	281	Rectifier	6	100
1N1344B	—	58	281	Rectifier	6	200
1N1345B	—	58	281	Rectifier	6	300
1N1346B	—	58	281	Rectifier	6	400
1N1347B	—	58	281	Rectifier	6	500
1N1348B	—	58	281	Rectifier	6	600
1N1763A	—	89	258	Rectifier	1	400
1N1764A	—	89	258	Rectifier	1	500
1N2858A	—	91	265	Rectifier	1	50
1N2859A	—	91	265	Rectifier	1	100
1N2860A	—	91	265	Rectifier	1	200
1N2861A	—	91	265	Rectifier	1	300
1N2862A	—	91	265	Rectifier	1	400
1N2863A	—	91	265	Rectifier	1	500
1N2864A	—	91	265	Rectifier	1	600
1N3193	—	41	294	Rectifier	0.75	200
1N3194	—	41	294	Rectifier	0.75	400
1N3195	—	41	294	Rectifier	0.75	600
1N3196	—	41	294	Rectifier	0.5	800
1N3253	—	41	294	Rectifier	0.75	200
1N3254	—	41	294	Rectifier	0.75	400
1N3255	—	41	294	Rectifier	0.75	600
1N3256	—	41	294	Rectifier	0.5	800
1N3563	—	41	294	Rectifier	0.4	1000
1N3879	—	726	323	Rectifier	6	50
1N3880	—	726	323	Rectifier	6	100
1N3881	—	726	323	Rectifier	6	200
1N3882	—	726	323	Rectifier	6	300
1N3883	—	726	323	Rectifier	6	400
1N3889	—	727	331	Rectifier	12	50
1N3890	—	727	331	Rectifier	12	100
1N3891	—	727	331	Rectifier	12	200
1N3892	—	727	331	Rectifier	12	300
1N3893	—	727	331	Rectifier	12	400
1N3899	—	728	339	Rectifier	20	50
1N3900	—	728	339	Rectifier	20	100
1N3901	—	728	339	Rectifier	20	200
1N3902	—	728	339	Rectifier	20	300
1N3903	—	728	339	Rectifier	20	400
1N3909	—	729	342	Rectifier	30	50

RCA Type No.	Former Type No.■	Data Sheet File No.	Page No.	Type of Device	Current (A)	Voltage (V)
1N3910	—	729	342	Rectifier	30	100
1N3911	—	729	342	Rectifier	30	200
1N3912	—	729	342	Rectifier	30	300
1N3913	—	729	342	Rectifier	30	400
1N5211	—	245	270	Rectifier	1	200
1N5212	—	245	270	Rectifier	1	400
1N5213	—	245	270	Rectifier	1	600
1N5214	—	245	270	Rectifier	0.75	800
1N5215	—	245	270	Rectifier	1	200
1N5216	—	245	270	Rectifier	1	400
1N5217	—	245	270	Rectifier	1	600
1N5218	—	245	270	Rectifier	0.75	800
1N5391	—	478	273	Rectifier	1.5	50
1N5392	—	478	273	Rectifier	1.5	100
1N5393	—	478	273	Rectifier	1.5	200
1N5394	—	478	273	Rectifier	1.5	300
1N5395	—	478	273	Rectifier	1.5	400
1N5396	—	478	273	Rectifier	1.5	500
1N5397	—	478	273	Rectifier	1.5	600
1N5398	—	478	273	Rectifier	1.5	800
1N5399	—	478	273	Rectifier	1.5	1000
2N681	—	96	225	SCR	25	25
2N682	—	96	225	SCR	25	50
2N683	—	96	225	SCR	25	100
2N684	—	96	225	SCR	25	150
2N685	—	96	225	SCR	25	200
2N686	—	96	225	SCR	25	250
2N687	—	96	225	SCR	25	300
2N688	—	96	225	SCR	25	400
2N689	—	96	225	SCR	25	500
2N690	—	96	225	SCR	25	600
2N1842A	—	28	234	SCR	16	25
2N1843A	—	28	234	SCR	16	50
2N1844A	—	28	234	SCR	16	100
2N1845A	—	28	234	SCR	16	150
2N1846A	—	28	234	SCR	16	200
2N1847A	—	28	234	SCR	16	250
2N1848A	—	28	234	SCR	16	300
2N1849A	—	28	234	SCR	16	400
2N1850A	—	28	234	SCR	16	500
2N3228	—	114	144	SCR	5	200
2N3525	—	114	144	SCR	5	400
2N3528	—	114	144	SCR	2	200
2N3529	—	114	144	SCR	2	400
2N3650	—	408	238	SCR	35	100
2N3651	—	408	238	SCR	35	200
2N3652	—	408	238	SCR	35	300
2N3653	—	408	238	SCR	35	400
2N3654	—	724	245	SCR	35	50
2N3655	—	724	245	SCR	35	100
2N3656	—	724	245	SCR	35	200
2N3657	—	724	245	SCR	35	300
2N3658	—	724	245	SCR	35	400
2N3668	—	116	203	SCR	12.5	100
2N3669	—	116	203	SCR	12.5	200
2N3670	—	116	203	SCR	12.5	400
2N3870	—	578	218	SCR	35	100
2N3871	—	578	218	SCR	35	200
2N3872	—	578	218	SCR	35	400
2N3873	—	578	218	SCR	35	600
2N3896	—	578	218	SCR	35	100
2N3897	—	578	218	SCR	35	200
2N3898	—	578	218	SCR	35	400
2N3899	—	578	218	SCR	35	600
2N4101	—	114	144	SCR	5	600
2N4102	—	114	144	SCR	2	600
2N4103	—	116	203	SCR	12.5	600
2N5441	—	593	55	Triac	40	200
2N5442	—	593	55	Triac	40	400
2N5443	—	593	55	Triac	40	600
2N5444	—	593	55	Triac	40	200
2N5445	—	593	55	Triac	40	400
2N5446	—	593	55	Triac	40	600
2N5567	—	457	92	Triac	10	200
2N5568	—	457	92	Triac	10	400

■ Applies to RCA 100, 40000, 41000, 43000, 44000, and 45000 Series numbers.

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RCA Type No.	Former Type No.■	Data Sheet File No.	Page No.	Type of Device	Current (A)	Voltage (V)
2N5569	–	457	92	Triac	10	200
2N5570	–	457	92	Triac	10	400
2N5571	–	458	85	Triac	15	200
2N5572	–	458	85	Triac	15	400
2N5573	–	458	85	Triac	15	200
2N5574	–	458	85	Triac	15	400
2N5754	–	414	28	Triac	2.5	100
2N5755	–	414	28	Triac	2.5	200
2N5756	–	414	28	Triac	2.5	400
2N5757	–	414	28	Triac	2.5	600
D1201A	44002	495	277	Rectifier	1	100
D1201B	44003	495	277	Rectifier	1	200
D1201D	44004	495	277	Rectifier	1	400
D1201F	44001	495	277	Rectifier	1	50
D1201M	44005	495	277	Rectifier	1	600
D1201N	44006	495	277	Rectifier	1	800
D1201P	44007	495	277	Rectifier	1	1000
D2101S	40892	522	298	Rectifier	1	700
D2103S	40891	522	298	Rectifier	3	700
D2103SF	40890	522	298	Rectifier	3	750
D2201A	44934	629	313	Rectifier	1	100
D2201B	44935	629	313	Rectifier	1	200
D2201D	44936	629	313	Rectifier	1	400
D2201F	44933	629	313	Rectifier	1	50
D2201M	44937	629	313	Rectifier	1	600
D2201N	44938	629	313	Rectifier	1	800
D2406A	43880	663	318	Rectifier	6	100
D2406B	43881	663	318	Rectifier	6	200
D2406C	43882	663	318	Rectifier	6	300
D2406D	43883	663	318	Rectifier	6	400
D2406F	43879	663	318	Rectifier	6	50
D2406M	43884	663	318	Rectifier	6	600
D2412A	43890	664	326	Rectifier	12	100
D2412B	43891	664	326	Rectifier	12	200
D2412C	43892	664	326	Rectifier	12	300
D2412D	43893	664	326	Rectifier	12	400
D2412F	43889	664	326	Rectifier	12	50
D2412M	43894	664	326	Rectifier	12	600
D2520A	43900	665	334	Rectifier	20	100
D2520B	43901	665	334	Rectifier	20	200
D2520C	43902	665	334	Rectifier	20	300
D2520D	43903	665	334	Rectifier	20	400
D2520F	43899	665	334	Rectifier	20	50
D2520M	43904	665	334	Rectifier	20	600
D2540A	40957	580	345	Rectifier	40	100
D2540B	40958	580	345	Rectifier	40	200
D2540D	40959	580	345	Rectifier	40	400
D2540F	40956	580	345	Rectifier	40	50
D2540M	40960	580	345	Rectifier	40	600
D2600EF	40644	354	303	Rectifier	1	550
D2601A	–	723	308	Rectifier	1	100
D2601B	TA7892	723	308	Rectifier	1	200
D2601D	TA7893	723	308	Rectifier	1	400
D2601DF	40643	354	303	Rectifier	1	450
D2601EF	40642	354	303	Rectifier	1	550
D2601F	–	723	308	Rectifier	1	50
D2601M	TA7894	723	308	Rectifier	1	600
D2601N	TA7895	723	308	Rectifier	1	800
D3202U	45412	577	350	Diac	2 pk	25-40
D3202Y	45411	577	350	Diac	2 pk	29-35
S2060A	106A	654	138	SCR	4	100
S2060B	106B	654	138	SCR	4	200
S2060C	106C	654	138	SCR	4	300
S2060D	106D	654	138	SCR	4	400
S2060E	106E	654	138	SCR	4	500
S2060F	106F	654	138	SCR	4	50
S2060M	106M	654	138	SCR	4	600
S2060Q	106Q	654	138	SCR	4	15
S2060Y	106Y	654	138	SCR	4	30
S2061A	107A	654	138	SCR	4	100
S2061B	107B	654	138	SCR	4	200
S2061C	107C	654	138	SCR	4	300
S2061D	107D	654	138	SCR	4	400
S2061E	107E	654	138	SCR	4	500
S2061F	107F	654	138	SCR	4	50

RCA Type No.	Former Type No.■	Data Sheet File No.	Page No.	Type of Device	Current (A)	Voltage (V)
S2061M	107M	654	138	SCR	4	600
S2061Q	107Q	654	138	SCR	4	15
S2061Y	107Y	654	138	SCR	4	30
S2062A	108A	654	138	SCR	4	100
S2062B	108B	654	138	SCR	4	200
S2062C	108C	654	138	SCR	4	300
S2062D	108D	654	138	SCR	4	400
S2062E	108E	654	138	SCR	4	500
S2062F	108F	654	138	SCR	4	50
S2062M	108M	654	138	SCR	4	600
S2062Q	108Q	654	138	SCR	4	15
S2062Y	108Y	654	138	SCR	4	30
S2400A	40942	567	151	SCR	4.5	100
S2400B	40493	567	151	SCR	4.5	200
S2400D	40944	567	151	SCR	4.5	400
S2400M	40945	567	151	SCR	4.5	600
S2600B	40654	496	156	SCR	7	200
S2600D	40655	496	156	SCR	7	400
S2600M	40833	496	156	SCR	7	600
S2610B	40658	496	156	SCR	3.3	200
S2610D	40659	496	156	SCR	3.3	400
S2610M	40835	496	156	SCR	3.3	600
S2620B	40656	496	156	SCR	7	200
S2620D	40657	496	156	SCR	7	400
S2620M	40834	496	156	SCR	7	600
S2710B	40504	266	164	SCR	1.7	200
S2710D	40505	266	164	SCR	1.7	400
S2710M	40506	266	164	SCR	1.7	600
S2800A	40867	501	166	SCR	8	100
S2800B	40868	501	166	SCR	8	200
S2800D	40869	501	166	SCR	8	400
S3700B	40553	306	172	SCR	5	200
S3700D	40554	306	172	SCR	5	400
S3700M	40555	306	172	SCR	5	600
S3701M	40768	476	192	SCR	5	600
S3702SF	40889	522	194	SCR	5	750
S3703SF	40888	522	194	SCR	5	750
S3704A	–	690	180	SCR	5	100
S3704B	–	690	180	SCR	5	200
S3704D	–	690	180	SCR	5	400
S3704M	–	690	180	SCR	5	600
S3704S	–	690	180	SCR	5	700
S3705M	40640	354	187	SCR	5	600
S3706M	40641	354	187	SCR	5	600
S3714A	–	690	180	SCR	5	100
S3714B	–	690	180	SCR	5	200
S3714D	–	690	180	SCR	5	400
S3714M	–	690	180	SCR	5	600
S3714S	–	690	180	SCR	5	700
S3800D	41023	639	199	ITR*	5	400
S3800E	41019	639	199	ITR*	5	500
S3800EF	41022	639	199	ITR*	5	550
S3800M	41021	639	199	ITR*	5	600
S3800MF	41018	639	199	ITR*	5	650
S3800S	41020	639	199	ITR*	5	700
S3800SF	41017	639	199	ITR*	5	750
S6200A	40749	418	210	SCR	20	100
S6200B	40750	418	210	SCR	20	200
S6200D	40751	418	210	SCR	20	400
S6200M	40752	418	210	SCR	20	600
S6210A	40753	418	210	SCR	20	100
S6210B	40754	418	210	SCR	20	200
S6210D	40755	418	210	SCR	20	400
S6210M	40756	418	210	SCR	20	600
S6220A	40757	418	210	SCR	20	100
S6220B	40758	418	210	SCR	20	200
S6220D	40759	418	210	SCR	20	400
S6220M	40760	418	210	SCR	20	600
S6400N	40937	578	218	SCR	35	800
S6410N	40938	578	218	SCR	35	800
S6420A	40680	578	218	SCR	35	100
S6420B	40681	578	218	SCR	35	200
S6420D	40682	578	218	SCR	35	400
S6420M	40683	578	218	SCR	35	600
S6420N	40952	578	218	SCR	35	800

■Applies to RCA 100, 4000, 41000, 43000, 44000, and 45000, Series numbers.

*Integrated thyristor and rectifier.

S6431M	40216	247	228	SCR	35	600
S7430M	40735	408	238	SCR	35	600
S7432M	–	724	245	SCR	35	600
T2300A	40525	470	33	Triac	2.5	100
T2300B	40526	470	33	Triac	2.5	200
T2300D	40527	470	33	Triac	2.5	400
T2301A	40766	431	40	Triac	2.5	100
T2301B	40691	431	40	Triac	2.5	200
T2301D	40692	431	40	Triac	2.5	400
T2302A	40528	470	33	Triac	2.5	100
T2302B	40529	470	33	Triac	2.5	200
T2302D	40530	470	33	Triac	2.5	400
T2304B	40769	441	41	Triac	0.5	200
T2304D	40770	441	41	Triac	0.5	400
T2305B	40771	441	41	Triac	0.5	200
T2305D	40772	441	41	Triac	0.5	400
T2306A	40696	406	47	Triac	2.5	100
T2306B	40697	406	47	Triac	2.5	200
T2306D	40698	406	47	Triac	2.5	400
T2310A	40531	470	33	Triac	1.6	470
T2310B	40532	470	33	Triac	1.6	200
T2310D	40533	470	33	Triac	1.6	400
T2311A	40767	431	40	Triac	1.6	100
T2311B	40761	431	40	Triac	1.6	200
T2311D	40762	431	40	Triac	1.6	400
T2312A	40534	470	33	Triac	1.9	100
T2312B	40535	470	33	Triac	1.9	200
T2312D	40536	470	33	Triac	1.9	400
T2313A	40684	414	28	Triac	1.9	100
T2313B	40685	414	28	Triac	1.9	200
T2313D	40686	414	28	Triac	1.9	400
T2313M	40687	414	28	Triac	1.9	600
T2316A	40693	406	47	Triac	2.5	100
T2316B	40694	406	47	Triac	2.5	200
T2316D	40695	406	47	Triac	2.5	400
T2500B	41014	615	49	Triac	6	200
T2500D	41015	615	49	Triac	6	400
T2700B	40429	351	62	Triac	6	200
T2700D	40430	351	62	Triac	6	400
T2706B	40727	406	47	Triac	6	200
T2706D	40728	406	47	Triac	6	400
T2710B	40502	351	62	Triac	3.3	200
T2710D	40503	351	62	Triac	3.3	400
T2716B	40729	406	47	Triac	3.3	200
T2716D	40730	406	47	Triac	3.3	400
T2800B	40668	364	69	Triac	8	200
T2800D	40669	364	69	Triac	8	400
T2800M	40670	364	69	Triac	8	600
T2801DF	40842	493	75	Triac	6	450
T2806B	40721	406	47	Triac	8	200
T2806D	40722	406	47	Triac	8	400
T2850A	40900	540	79	Triac	8	100
T2850B	40901	540	79	Triac	8	200
T2850D	40902	540	79	Triac	8	400
T4100M	40797	458	85	Triac	15	600
T4101M	40795	457	92	Triac	10	600
T4103B	40783	443	99	Triac	15	200
T4103D	40784	443	99	Triac	15	400
T4104B	40779	443	99	Triac	10	200
T4104D	40780	443	99	Triac	10	400
T4105B	40775	443	99	Triac	6	200
T4105D	40776	443	99	Triac	6	400
T4106B	40711	406	47	Triac	15	200
T4106D	40712	406	47	Triac	15	400
T4107B	40717	406	47	Triac	10	200
T4107D	40718	406	47	Triac	10	400
T4110M	40798	458	85	Triac	15	600
T4111M	40796	457	92	Triac	10	600
T4113B	40785	443	99	Triac	15	200
T4113D	40786	443	99	Triac	15	400
T4114B	40781	443	99	Triac	10	200
T4114D	40782	443	99	Triac	10	400
T4115B	40777	443	99	Triac	6	200
T4115D	40778	443	99	Triac	6	400
T4116B	40713	406	47	Triac	15	200
T4116D	40714	406	47	Triac	15	400
T4117B	40719	406	47	Triac	10	200
T4117D	40720	406	47	Triac	10	400
T4120B	40802	458	85	Triac	15	200
T4120D	40803	458	85	Triac	15	400
T4120M	40804	458	85	Triac	15	600
T4121B	40799	457	92	Triac	10	200
T4121D	40800	457	92	Triac	10	400
T4121M	40801	457	92	Triac	10	600
T4706B	40715	406	47	Triac	15	200
T4706D	40716	406	47	Triac	15	400
T6400N	40925	593	55	Triac	40	800
T6401B	40660	459	107	Triac	30	200
T6401D	40661	459	107	Triac	30	400
T6401M	40671	459	107	Triac	30	600
T6404B	40791	487	114	Triac	40	200
T6404D	40792	487	114	Triac	40	400
T6405B	40787	487	114	Triac	25	200
T6405D	40788	487	114	Triac	25	400
T6406B	40699	406	47	Triac	40	200
T6406D	40700	406	47	Triac	40	400
T6406M	40701	406	47	Triac	40	600
T6407B	40705	406	47	Triac	30	200
T6407D	40706	406	47	Triac	30	400
T6407M	40709	406	47	Triac	30	600
T6410N	40926	593	55	Triac	40	800
T6411B	40662	459	107	Triac	30	200
T6411D	40663	459	107	Triac	30	400
T6411M	40672	459	107	Triac	30	600
T6414B	40793	487	114	Triac	40	200
T6414D	40794	487	114	Triac	40	400
T6415B	40789	487	114	Triac	25	200
T6415D	40790	487	114	Triac	25	400
T6416B	40702	406	47	Triac	40	200
T6416D	40703	406	47	Triac	40	400
T6416M	40704	406	47	Triac	40	600
T6417B	40707	406	47	Triac	30	200
T6417D	40708	406	47	Triac	30	400
T6417M	40710	406	47	Triac	30	600
T6420B	40688	593	55	Triac	40	200
T6420D	40689	593	55	Triac	40	400
T6420M	40690	593	55	Triac	40	600
T6420N	40927	593	55	Triac	40	800
T6421B	40805	459	107	Triac	30	200
T6421D	40806	459	107	Triac	30	400
T6421M	40807	459	107	Triac	30	600
T8401B	41029	725	122	Triac	60	200
T8401D	41030	725	122	Triac	60	400
T8401M	41031	725	122	Triac	60	600
T8411B	41032	725	122	Triac	60	200
T8411D	41033	725	122	Triac	60	400
T8411M	41034	725	122	Triac	60	600
T8421B	41035	725	122	Triac	60	200
T8421D	41036	725	122	Triac	60	400
T8421M	41037	725	122	Triac	60	600
T8430B	40916	549	130	Triac	80	200
T8430D	40917	549	130	Triac	80	400
T8430M	40918	549	130	Triac	80	600
T8440B	40919	549	130	Triac	80	200
T8440D	40920	549	130	Triac	80	400
T8440M	40921	549	130	Triac	80	600
T8450B	40922	549	130	Triac	80	200
T8450D	40923	549	130	Triac	80	400
T8450M	40924	549	130	Triac	80	600

■Applies to RCA 100, 40000, 41000, 43000, 44000, and 45000 Series numbers.

RCA Thyristors/Rectifiers Type-Number Cross-Reference Guide

(Old numbers to NEW numbers)

Former RCA Type No.	NEW RCA Type No.	Data Sheet File No.	Page No.	Type of Device	Current (A)	Voltage (V)
RCA106A	S2060A	654	138	SCR	4	100
RCA106B	S2060B	654	138	SCR	4	200
RCA106C	S2060C	654	138	SCR	4	300
RCA106D	S2060D	654	138	SCR	4	400
RCA106E	S2060E	654	138	SCR	4	500
RCA106F	S2060F	654	138	SCR	4	50
RCA106Q	S2060Q	654	138	SCR	4	15
RCA106M	S2060M	654	138	SCR	4	600
RCA106Y	S2060Y	654	138	SCR	4	30
RCA107A	S2061A	654	138	SCR	4	100
RCA107B	S2061B	654	138	SCR	4	200
RCA107C	S2061C	654	138	SCR	4	300
RCA107D	S2061D	654	138	SCR	4	400
RCA107E	S2061E	654	138	SCR	4	500
RCA107F	S2061F	654	138	SCR	4	50
RCA107Q	S2061Q	654	138	SCR	4	15
RCA107M	S2061M	654	138	SCR	4	600
RCA107Y	S2061Y	654	138	SCR	4	30
RCA108A	S2062A	654	138	SCR	4	100
RCA108B	S2062B	654	138	SCR	4	200
RCA108C	S2062C	654	138	SCR	4	300
RCA108D	S2062D	654	138	SCR	4	400
RCA108E	S2062E	654	138	SCR	4	500
RCA108F	S2062F	654	138	SCR	4	50
RCA108Q	S2062Q	654	138	SCR	4	15
RCA108M	S2062M	654	138	SCR	4	600
RCA108Y	S2062Y	654	138	SCR	4	30
40216	S6431M	247	228	SCR	35	600
40429	T2700B	351	62	Triac	6	200
40430	T2700D	351	62	Triac	6	400
40502	T2710B	351	62	Triac	3.3	200
40503	T2710D	351	62	Triac	3.3	400
40504	S2710B	266	164	SCR	1.7	200
40505	S2710D	266	164	SCR	1.7	400
40506	S2710M	266	164	SCR	1.7	600
40525	T2300A	470	33	Triac	2.5	100
40526	T2300B	470	33	Triac	2.5	200
40527	T2300D	470	33	Triac	2.5	400
40528	T2302A	470	33	Triac	2.5	100
40529	T2302B	470	33	Triac	2.5	200
40530	T2302D	470	33	Triac	2.5	400
40531	T2310A	470	33	Triac	1.6	100
40532	T2310B	470	33	Triac	1.6	200
40533	T2310D	470	33	Triac	1.6	400
40534	T2312A	470	33	Triac	1.9	100
40535	T2312B	470	33	Triac	1.9	200
40536	T2312D	470	33	Triac	1.9	400
40553	S3700B	306	172	SCR	5	200
40554	S3700D	306	172	SCR	5	400
40555	S3700M	306	172	SCR	5	600
40640	S3705M	354	187	SCR	5	600
40641	S3706M	354	187	SCR	5	600
40642	D2601EF	354	303	Rectifier	1	550
40643	D2601DF	354	303	Rectifier	1	450
40644	D2600EF	354	303	Rectifier	1	550
40654	S2600B	496	156	SCR	7	200
40655	S2600D	496	156	SCR	7	400
40656	S2620B	496	156	SCR	7	200
40657	S2620D	496	156	SCR	7	400
40658	S2610B	496	156	SCR	3.3	200
40659	S2610D	496	156	SCR	3.3	400
40660	T6401B	459	107	Triac	30	200
40661	T6401D	459	107	Triac	30	400
40662	T6411B	459	107	Triac	30	200
40663	T6411D	459	107	Triac	30	400
40668	T2800B	364	69	Triac	8	200
40669	T2800D	364	69	Triac	8	400
40670	T2800M	364	69	Triac	8	600
40671	T6401M	459	107	Triac	30	600
40672	T6411M	459	107	Triac	30	600
40680	S6420A	578	218	SCR	35	100
40681	S6420B	578	218	SCR	35	200
40682	S6420D	578	218	SCR	35	400
40683	S6420M	578	218	SCR	35	600
40684	T2313A	414	28	Triac	1.9	100
40685	T2313B	414	28	Triac	1.9	200
40686	T2313D	414	28	Triac	1.9	400
40687	T2313M	414	28	Triac	1.9	600
40688	T6420B	593	55	Triac	40	200
40689	T6420D	593	55	Triac	40	400
40690	T6420M	593	55	Triac	40	600
40691	T2301B	431	40	Triac	2.5	200
40692	T2301D	431	40	Triac	2.5	400
40693	T2316A	406	47	Triac	2.5	100
40694	T2316B	406	47	Triac	2.5	200
40695	T2316D	406	47	Triac	2.5	400
40696	T2306A	406	47	Triac	2.5	100
40697	T2306B	406	47	Triac	2.5	200
40698	T2306D	406	47	Triac	2.5	400
40699	T6406B	406	47	Triac	40	200
40700	T6406D	406	47	Triac	40	400
40701	T6406M	406	47	Triac	40	600
40702	T6416B	406	47	Triac	40	200
40703	T6416D	406	47	Triac	40	400
40704	T6416M	406	47	Triac	40	600
40705	T6407B	406	47	Triac	30	200
40706	T6407D	406	47	Triac	30	400
40707	T6417B	406	47	Triac	30	200
40708	T6417D	406	47	Triac	30	400
40709	T6407M	406	47	Triac	30	600
40710	T6417M	406	47	Triac	30	600
40711	T4106B	406	47	Triac	15	200
40712	T4106D	406	47	Triac	15	400
40713	T4116B	406	47	Triac	15	200
40714	T4116D	406	47	Triac	15	400
40715	T4706B	406	47	Triac	15	200
40716	T4706D	406	47	Triac	15	400
40717	T4107B	406	47	Triac	10	200
40718	T4107D	406	47	Triac	10	400
40719	T4117B	406	47	Triac	10	200
40720	T4117D	406	47	Triac	10	400
40721	T2806B	406	47	Triac	8	200
40722	T2806D	406	47	Triac	8	400
40727	T2706B	406	47	Triac	6	200
40728	T2706D	406	47	Triac	6	400
40729	T2716B	406	47	Triac	3.3	200
40730	T2716D	406	47	Triac	3.3	400
40735	S7430M	408	238	SCR	35	600
40749	S6200A	418	210	SCR	20	100
40750	S6200B	418	210	SCR	20	200
40751	S6200D	418	210	SCR	20	400
40752	S6200M	418	210	SCR	20	600
40753	S6210A	418	210	SCR	20	100
40754	S6210B	418	210	SCR	20	200
40755	S6210D	418	210	SCR	20	400
40756	S6210M	418	210	SCR	20	600
40757	S6220A	418	210	SCR	20	100
40758	S6220B	418	210	SCR	20	200
40759	S6220D	418	210	SCR	20	400
40760	S6220M	418	210	SCR	20	600
40761	T2311B	431	40	Triac	1.6	200
40762	T2311D	431	40	Triac	1.6	400
40766	T2301A	431	40	Triac	2.5	100
40767	T2311A	431	40	Triac	1.6	100
40768	S3701M	476	192	SCR	5	600
40769	T2304B	441	41	Triac	0.5	200
40770	T2304D	441	41	Triac	0.5	400
40771	T2305B	441	41	Triac	0.5	200
40772	T2305D	441	41	Triac	0.5	400
40775	T4105B	443	99	Triac	6	200

RCA Thyristors/Rectifiers Type-Number Cross-Reference Guide [cont'd]

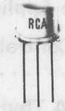
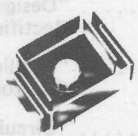
(Old numbers to NEW numbers)

Former RCA Type No.	NEW RCA Type No.	Data Sheet File No.	Page No.	Type of Device	Current (A)	Voltage (V)
40776	T4105D	443	99	Triac	6	400
40777	T4115B	443	99	Triac	6	200
40778	T4115D	443	99	Triac	6	400
40779	T4104B	443	99	Triac	10	200
40780	T4104D	443	99	Triac	10	400
40781	T4114B	443	99	Triac	10	200
40782	T4114D	443	99	Triac	10	400
40783	T4103B	443	99	Triac	15	200
40784	T4103D	443	99	Triac	15	400
40785	T4113B	443	99	Triac	15	200
40786	T4113D	443	99	Triac	15	400
40787	T6405B	487	114	Triac	25	200
40788	T6405D	487	114	Triac	25	400
40789	T6415B	487	114	Triac	25	200
40790	T6415D	487	114	Triac	25	400
40791	T6404B	487	114	Triac	40	200
40792	T6404D	487	114	Triac	40	400
40793	T6414B	487	114	Triac	40	200
40794	T6414D	487	114	Triac	40	400
40795	T4101M	457	92	Triac	10	600
40796	T4111M	457	92	Triac	10	600
40797	T4100M	458	85	Triac	15	600
40798	T4110M	458	85	Triac	15	600
40799	T4121B	457	92	Triac	10	200
40800	T4121D	457	92	Triac	10	400
40801	T4121M	457	92	Triac	10	600
40802	T4120B	458	85	Triac	15	200
40803	T4120D	458	85	Triac	15	400
40804	T4120M	458	85	Triac	15	600
40805	T6421B	459	107	Triac	30	200
40806	T6421D	459	107	Triac	30	400
40807	T6421M	459	107	Triac	30	600
40833	S2600M	496	156	SCR	7	600
40834	S2620M	496	156	SCR	7	600
40835	S2610M	496	156	SCR	3.3	600
40842	T2801DF	493	75	Triac	6	450
40867	S2800A	501	166	SCR	8	100
40868	S2800B	501	166	SCR	8	200
40869	S2800D	501	166	SCR	8	400
40888	S3703SF	522	194	SCR	5	750
40889	S3702SF	522	194	SCR	5	750
40890	D2103SF	522	298	Rectifier	3	750
40891	D2103S	522	298	Rectifier	3	700
40892	D2101S	522	298	Rectifier	1	700
40900	T2850A	540	79	Triac	8	100
40901	T2850B	540	79	Triac	8	200
40902	T2850D	540	79	Triac	8	400
40916	T8430B	549	130	Triac	80	200
40917	T8430D	549	130	Triac	80	400
40918	T8430M	549	130	Triac	80	600
40919	T8440B	549	130	Triac	80	200
40920	T8440D	549	130	Triac	80	400
40921	T8440M	549	130	Triac	80	600
40922	T8450B	549	130	Triac	80	200
40923	T8450D	549	130	Triac	80	400
40924	T8450M	549	130	Triac	80	600
40925	T6400N	593	55	Triac	40	800
40926	T6410N	593	55	Triac	40	800
40927	T6420N	593	55	Triac	40	800
40937	S6400N	578	218	SCR	35	800
40938	S6410N	578	218	SCR	35	800
40942	S2400A	567	151	SCR	4.5	100
40943	S2400B	567	151	SCR	4.5	200
40944	S2400D	567	151	SCR	4.5	400
40945	S2400M	567	151	SCR	4.5	600
40952	S6420N	578	218	SCR	35	800
40956	D2540F	580	345	Rectifier	40	50
40957	D2540A	580	345	Rectifier	40	100
40958	D2540B	580	345	Rectifier	40	200
40959	D2540D	580	345	Rectifier	40	400
40960	D2540M	580	345	Rectifier	40	600
41014	T2500B	615	49	Triac	6	200
41015	T2500D	615	49	Triac	6	400
41017	S3800SF	639	199	ITR*	5	750
41018	S3800MF	639	199	ITR*	5	650
41019	S3800E	639	199	ITR*	5	500
41020	S3800S	639	199	ITR*	5	700
41021	S3800M	639	199	ITR*	5	600
41022	S3800EF	639	199	ITR*	5	550
41023	S3800D	639	199	ITR*	5	400
41029	T8401B	725	122	Triac	60	200
41030	T8401D	725	122	Triac	60	400
41031	T8401M	725	122	Triac	60	600
41032	T8411B	725	122	Triac	60	200
41033	T8411D	725	122	Triac	60	400
41034	T8411M	725	122	Triac	60	600
41035	T8421B	725	122	Triac	60	200
41036	T8421D	725	122	Triac	60	400
41037	T8421M	725	122	Triac	60	600
43879	D2406F	663	318	Rectifier	6	50
43880	D2406A	663	318	Rectifier	6	100
43881	D2406B	663	318	Rectifier	6	200
43882	D2406C	663	318	Rectifier	6	300
43883	D2406D	663	318	Rectifier	6	400
43884	D2406M	663	318	Rectifier	6	600
43889	D2412F	664	326	Rectifier	12	50
43890	D2412A	664	326	Rectifier	12	100
43891	D2412B	664	326	Rectifier	12	200
43892	D2412C	664	326	Rectifier	12	300
43893	D2412D	664	326	Rectifier	12	400
43894	D2412M	664	326	Rectifier	12	600
43899	D2520F	665	334	Rectifier	20	50
43900	D2520A	665	334	Rectifier	20	100
43901	D2520B	665	334	Rectifier	20	200
43902	D2520C	665	334	Rectifier	20	300
43903	D2520D	665	334	Rectifier	20	400
43904	D2520M	665	334	Rectifier	20	600
44001	D1201F	495	278	Rectifier	1	50
44002	D1201A	495	278	Rectifier	1	100
44003	D1201B	495	278	Rectifier	1	200
44004	D1201D	495	278	Rectifier	1	400
44005	D1201M	495	278	Rectifier	1	600
44006	D1201N	495	278	Rectifier	1	800
44007	D1201P	495	278	Rectifier	1	1000
44933	D2201F	629	313	Rectifier	1	50
44934	D2201A	629	313	Rectifier	1	100
44935	D2201B	629	313	Rectifier	1	200
44936	D2201D	629	313	Rectifier	1	400
44937	D2201M	629	313	Rectifier	1	600
44938	D2201N	629	313	Rectifier	1	800
45411	D3202Y	577	350	Diac	2 pk	29-35
45412	D3202U	577	350	Diac	2 pk	25-40
TA7892	D2601B	723	308	Rectifier	1	200
TA7893	D2601D	723	308	Rectifier	1	400
TA7894	D2601M	723	308	Rectifier	1	600
TA7895	D2601N	723	308	Rectifier	1	800

* Integrated thyristor and rectifier.

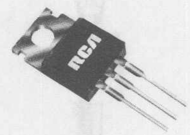
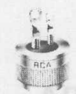
Application Notes for Thyristors, Rectifiers and Diacs

Triac Product Matrix

RCA Triacs			 Modified TO-5						 Mod. TO-5 With Heat Radiator	
STANDARD	$I_{T(RMS)}$		2.5A	2.5A	2.5A	2.5A	2.5A	2.5A	2.5A	2.5A
	I_{TSM}		25A	25A	25A	25A	25A	25A	25A	25A
	V_{DROM}(V)	100	T2300A	T2301A	T2302A	2N5754	T2313A	T2310A	T2312A	T2311A
		200	T2300B	T2301B	T2302B	2N5755	T2313B	T2310B	T2312B	T2311B
		400	T2300D	T2301D	T2302D	2N5756	T2313D	T2310D	T2312D	T2311D
		450								
		600				2N5757	T2313M			
		800								
	I_{GT}(mA)									
		1+, 111−	3	4	10	25	25	3	10	4
		1−, 111+	3	4	10	40	40	3	10	4
	V_{GT}(V)									
		All Modes	2.2	2.2	2.2	2.2	2.2	2.2	2.2	2.2
		File No.	470	431	470	414	414	470	470	431
		Page No.	33	40	33	28	28	33	33	40
ZERO VOLTAGE SWITCH	V_{DROM}(V)	100				T2306A	T2316A			
		200				T2306B	T2316B			
		400				T2306D	T2316D			
		450								
		600								
	I_{GT}(mA)									
		1+, 111−				45	45			
	V_{GT}(V)									
		1+, 111+				1.5	1.5			
		File No.				406	406			
		Page No.				47	47			
400-HZ OPERATION	$I_{T(RMS)}$				0.5A	0.5A				
	V_{DROM}(V)	200			T2304B	T2305B				
		400			T2304D	T2305D				
	I_{GT}(mA)									
		1+, 111−			10	25				
		1−, 111+			10	40				
	V_{GT}(V)									
		All Modes			2.2	2.2				
		File No.			441	441				
		Page No.			41	41				

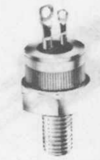
Triac Product Matrix (cont'd)

RCA Triacs

			TO-66		TO-66 With Heat Radiator	TO-220AB VERSAWATT				Press Fit		
												
STANDARD	I_T(RMS)		6.0A	15.0A	6.0A	6A	6A	8.0A	ISOWATT 8A		10.0A	15.0A
	I_{TSM}		100A	100A	100A	60A	100A	100A	100A		100A	100A
	V_{DROM}(V)	100							T2850A			
		200	T2700B		T2710B	T2500B		T2800B	T2850B		2N5567	2N5571
		400	T2700D		T2710D	T2500D		T2800D	T2850D		2N5568	2N5572
		450					T2801DF					
		600						T2800M			T4101M	T4100M
		800										
	I_{GT}(mA)											
		1+, 111–	25		25	25	80	25	25		25	50
		1–, 111+	40		40	60	–	60	60		40	80
	V_{GT}(V)											
		All Modes	2.2		2.2	2.5	4.0	2.5	2.5		2.5	2.5
		File No.	351		351	615	493	364	540		457	458
		Page No.	62		62	49	75	62	79		92	85
ZERO VOLTAGE SWITCH	V_{DROM}(V)	100										
		200	T2706B	T4706B	T2716B			T2806B			T4107B	T4106B
		400	T2706D	T4706D	T2716D			T2806D			T4107D	T4106D
		450										
		600										
	I_{GT}(mA)											
		1+, 111–	45	45	45			45			45	45
	V_{GT}(V)											
		1+, 111+	1.5	1.5	1.5			1.5			1.5	1.5
		File No.	406	406	406			406			406	406
		Page No.	47	47	47			69			69	69
400-HZ OPERATION	I_T(RMS)									6A	10.A	15.0A
	V_{DROM}(V)											
		200								T4105B	T4104B	T4103B
		400								T4105D	T4104D	T4103D
	I_{GT}(mA)											
		1+, 111–								50	50	50
		1–, 111+								80	80	80
	V_{GT}(V)											
		All Modes								2.5	2.5	2.5
		File No.								443	443	443
		Page No.								99	99	99

*ISOWATT – Mounting tab electrically isolated from electrodes

Triac Product Matrix (cont'd)

RCA Triacs			Stud			Isolated Stud		Press Fit		Stud	
											
STANDARD	$I_{T(RMS)}$			10.0A	15.0A	10.0A	15.0A	30.0A	40.0A	30.0A	40.0A
	I_{TSM}			100A	100A	100A	100A	300A	300A	300A	300A
	V_{DROM}(V)	100									
		200		2N5569	2N5573	T4121B	T4120B	T6401B	2N5441	T6411B	2N5444
		400		2N5570	2N5574	T4121D	T4120D	T6401D	2N5442	T6411D	2N5445
		450									
		600		T4111M	T4110M	T4121M	T4120M	T6401M	2N5443	T6411M	2N5446
		800							T6400N		T6410N
	I_{GT}(mA)										
		I+, III−		25	50	25	50	50	50	50	50
		I−, III		40	80	40	80	80	80	80	80
	V_{GT}(V)										
		All Modes		2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
		File No.		457	458	457	458	459	593	459	593
		Page No.		92	85	92	85	107	55	107	55
ZERO VOLTAGE SWITCH	V_{DROM}(V)										
		100									
		200		T4117B	T4116B			T6407B	T6406B	T6417B	T6416B
		400		T4117D	T4116D			T6407D	T6406D	T6417D	T6416D
		450									
		600						T6407M	T6406M	T6417M	T6416M
	I_{GT}(mA)										
		I+, III−		45	45			45	45	45	45
	V_{GT}(V)										
		I+, III+		1.5	1.5			1.5	1.5	1.5	1.5
		File No.		406	406			406	406	406	406
		Page No.		69	69			47	47	47	47
400-HZ OPERATION	$I_{T(RMS)}$		6A	10.0A	15.0A			25.0A	40.0A	25.0A	40.0A
	V_{DROM}(V)	200	T4115B	T4114B	T4113B			T6405B	T6404B	T6415B	T6414B
		400	T4115D	T4114D	T4113D			T6405D	T6404D	T6415D	T6414D
	I_{GT}(mA)										
		I+, III−	50	50	50			80	80	80	80
		I−, III+	80	80	80			120	120	120	120
	V_{GT}(V)										
		All Modes	2.5	2.5	2.5			3.0	3.0	3.0	3.0
		File No.	443	443	443			487	487	487	487
		Page No.	99	99	99			114	114	114	114

Triac Product Matrix (cont'd)

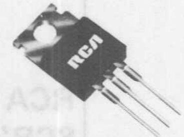
RCA Triacs			Isolated Stud 		Press Fit K, K-1 		Stud L, L-1 		Iso. Stud M, M-1 	
STANDARD	I_{T}(RMS)		30.0A	40.0A	60A	80A	60A	80A	60A	80A
	I_{TSM}		300A	300A	600A	850A	600A	850A	600A	850A
	V_{DROM}(V)	100								
		200	T6421B	T6420B	T8401B	T8430B	T8411B	T8440B	T8421B	T8450B
		400	T6421D	T6420D	T8401D	T8430D	T8411D	T8440D	T8421D	T8450D
		450								
		600	T6421M	T6420M	T8401M	T8430M	T8411M	T8440M	T8421M	T8450M
		800		T6420N						
	I_{GT}(mA)									
		1+, 111−	50	50	75	75	75	75	75	75
		1−, 111+	80	80	150	150	150	150	150	150
	V_{GT}(V)									
		All Modes	2.5	2.5	2.8	2.5	2.8	2.5	2.8	2.5
		File No.	459	593	725	549	725	549	725	549
		Page No.	107	55	122	130	122	130	122	130
ZERO VOLTAGE SWITCH	V_{DROM}(V)									
		100								
		200								
		400								
		450								
		600								
	I_{GT}(mA)									
		1+, 111−								
	V_{GT}(V)									
		1+, 111+								
		File No.								
		Page No.								
400-HZ OPERATION	I_{T}(RMS)									
	V_{DROM}(V)	200								
		400								
	I_{GT}(mA)									
		1+, 111−								
		1−, 111+								
	V_{GT}(V)									
		All Modes								
		File No.								
		Page No.								

Note: K-1, L-1, and M-1 packages have factory-attached flexible leads for main terminal 1 and 2; they are used for T8401, T8411, and T8421 series, respectively.

SCR Product Matrix

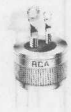
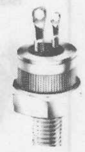
RCA SCR's		TO-8 			TO-66 					
$I_{T(RMS)}$		2.0A	4.5A	5.0A	FTO 5.0A	FTO 5.0A	FTO 5A	FTO 5.0A	FTO 5.0A	FTO 5.0A
I_{TSM}		60A	200A	60A	80A	80A	80A	75A(I_{PM})	50A	50A
V_{DROM}	15									
V_{RROM}(V)	25									
	30									
	50									
	100		S2400A				S3704A			
	150									
	200	2N3528	S2400B	2N3228		S3700B	S3704B			
	250									
	300									
	400	2N3529	S2400D	2N3525		S3700D	S3704D			
	500									
	600	2N4102	S2400M	2N4101	S3705M S3706M	S3700M	S3704M	S3701M		
	700						S3704S		S3702S	
	750									S3703SF
	800									
I_{GT}(mA)		15	15	15	30	40	40	35	45	40
V_{GT}(V)		2	2	2	4	3.5	3.5	4	4	4
	File No.	114	567	114	354	306	690	476	522	522
	Page No.	144	151	144	187	172	180	192	194	194

FTO – Fast Turn - Off

RCA SCR'S		TO-66 With Heat Rad.		Low Profile Mod. TO-5	TO-5 With Heat Rad.	TO-5 With Heat Spreader	TO-220AB			
							 VERSAWATT			
$I_{T(RMS)}$		5.0A	FTO 5A	7.0A	3.3A	7.0A	4.0A	4.0A	4A	8.0A
I_{TSM}		60A	80A	100A	100A	100A	35A	35A	35A	100A
V_{DROM} V_{RROM}(V)	15						S2060Q	S2061Q	S2062Q	
	25									
	30						S2060Y	S2061Y	S2062Y	
	50						S2060F	S2061F	S2062F	
	100		S3714A				S2060A	S2061A	S2062A	S2800A
	150									
	200	S2710B	S3714B	S2600B	S2610B	S2620B	S2060B	S2061B	S2062B	S2800B
	250									
	300						S2060C	S2061C	S2062C	
	400	S2710D	S3714D	S2600D	S2610D	S2620D	S2060D	S2061D	S2062D	S2800D
	500						S2060E	S2061E	S2062E	
	600	S2710M	S3714M	S2600M	S2610M	S2620M	S2060M	S2061M	S2062M	
	700		S3714S							
	750									
	800									
I_{GT}(mA)		15	40	15	15	15	0.2	0.5	2	15
V_{GT}(V)		2	3.5	1.5	1.5	1.5	0.8	0.8	0.8	1.5
	File No.	266	690	496	496	496	654	654	654	501
	Page No.	164	180	156	156	156	138	138	138	166

FTO – Fast Turn-Off

SCR Product Matrix (cont'd)

RCA SCR's		TO-3	Press Fit		Stud	
						
I_T(RMS)		12.5A	20.0A	35.0A	20.0A	35.0A
I_{TSM}		200A	200A	350A	200A	350A
V_{DROM}	15					
V_{RROM}(V)	25					
	30					
	50					
	100	2N3668	S6200A	2N3870	S6210A	2N3896
	150					
	200	2N3669	S6200B	2N3871	S6210B	2N3897
	250					
	300					
	400	2N3670	S6200D	2N3872	S6210D	2N3898
	500					
	600	2N4103	S6200M	2N3873	S6210M	2N3899
	700					
	750					
	800			S6400N		S6410N
I_{GT}(mA)		40	15	40	15	40
V_{GT}(V)		2	2	2	2	2
	File No.	116	418	578	418	578
	Page No.	203	210	218	210	218

SCR Product Matrix (cont'd)

RCA SCR's		Isolated Stud 		TO-48 				
I_T(RMS)		20.0A	35.0A	16.0A	25.0A	Pul. Mod. 35.0A	FTO 35.0A	FTO 35A
I_{TSM}		200A	350A	125A	150A	150A	180A	250A
V_{DROM}	15							
V_{RROM}(V)	25			2N1842A	2N681			
	30							
	50			2N1843A	2N682			2N3654
	100	S6220A	S6420A	2N1844A	2N683		2N3650	2N3655
	150			2N1845A	2N684			
	200	S6220B	S6420B	2N1846A	2N685		2N3651	2N3656
	250			2N1847A	2N686			
	300			2N1848A	2N687		2N3652	2N3657
	400	S6220D	S6420D	2N1849A	2N688		2N3653	2N3658
	500			2N1850A	2N689			
	600	S6220M	S6420M		2N690	S6431M	S7430M	S7432M
	700							
	750							
	800		S6420N					
I_{GT}(mA)		15	40	45	25	80	180	180
V_{GT}(V)		2	2	3.5	3	2	3	3
	File No.	418	578	28	96	247	408	724
	Page No.	210	218	234	225	228	238	245

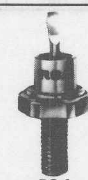
FTO – Fast Turn-Off

Rectifier Product Matrix

RCA Rectifiers

		DO-1				DO-26			
I_O		0.75A	0.75A	1A	1A	0.75A	0.75A Insu-lated	1A	1A Insu-lated
I_{FSM}		15A	15A	35A	35A	35A	35A	50A	50A
$V_{RRM}(V)$	50		1N536		1N2858A				
	100	1N440B	1N537		1N2859A				
	200	1N441B	1N538		1N2860A	1N3193	1N3253	1N5211	1N5215
	300	1N442B	1N539		1N2861A				
	400	1N443B	1N540	1N1763A	1N2862A	1N3194	1N3254	1N5212	1N5216
	500	1N444B	1N1095	1N1764A	1N2863A				
	600	1N445B	1N547		1N2864A	1N3195	1N3255	1N5213	1N5217
	800					1N3196	1N3256	1N5214	1N5218
	1000						1N3563		
	File No.	5	3	89	91	41	41	245	245
	Page No.	252	255	258	265	294	294	270	270

RCA Rectifiers

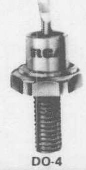


		Plastic	DO-15 (Plastic)	DO-4		DO-5	
I_O		1A	1.5A	6A	12A	20A	40A
I_{FSM}		30A	50A	160A	240A	350A	800A
$V_{RRM}(V)$	50	D1201F	1N5391	1N1341B	1N1199A	1N248C	1N1183A
	100	D1201A	1N5392	1N1342B	1N1200A	1N249C	1N1184A
	200	D1201B	1N5393	1N1344B	1N1202A	1N250C	1N1186A
	300		1N5394	1N1345B	1N1203A	1N1195A	1N1187A
	400	D1201D	1N5395	1N1346B	1N1204A	1N1196A	1N1188A
	500		1N5396	1N1347B	1N1205A	1N1197A	1N1189A
	600	D1201M	1N5397	1N1348B	1N1206A	1N1198A	1N1190A
	800	D1201N	1N5398				
	1000	D1201P	1N5399				
	File No.	495	478	58	20	6	38
	Page No.	277	273	281	283	287	291

Rectifier Product Matrix (cont'd)

Fast Recovery Types






RCA Rectifiers		DO-26	Plastic	DO-4				DO-5			
I_O		1A	1A	6A	6A	12A	12A	20A	20A	30A	40A
I_{FSM}		35A	50A	75A	125A	150A	250A	225A	300A	300A	700A
V_{RRM}(V)	50	D2601F	D2201F	1N3879	D2406F	1N3889	D2412F	1N3899	D2520F	1N3909	D2540F
	100	D2601A	D2201A	1N3880	D2406A	1N3890	D2412A	1N3900	D2520A	1N3910	D2540A
	200	D2601B	D2201B	1N3881	D2406B	1N3891	D2412B	1N3901	D2520B	1N3911	D2540B
	300			1N3882	D2406C	1N3892	D2412C	1N3902	D2520C	1N3912	
	400	D2601D	D2201D	1N3883	D2406D	1N3893	D2412D	1N3903	D2520D	1N3913	D2540D
	500										
	600	D2601M	D2201M		D2406M		D2412M		D2520M		D2540M
	800	D2601N	D2201N								
	1000										
Reverse Recovery Time trr											
	Typ.	200 ns.	200 ns.	–	200 ns.	–	200 ns.	–	200 ns.	–	200 ns.
	Max.	500 ns.	500 ns.	200 ns.	350 ns.	200 ns.	350 ns.	200 ns.	350 ns.	200 ns.	350 ns.
	File No.	723	629	726	663	727	664	728	665	729	580
	Page No.	308	313	323	318	331	326	339	334	342	345

For Horizontal - Deflection Circuits



RCA Rectifiers	DO-26			DO-1		DO-15 (Plastic)
I_o	1A	1A	1A	–	–	1A
I_{FSM}	70A	10A	20A	70A	30A	50A
Trace	D2601EF			D2103SF		D2201M
Commutating		D2601DF		D2103S		D2201M
Linearity			D2600EF			D2201B
Regulator						D2201B
Clamp					D2101S	
File No.	354	354	354	522	522	629
Page No.	303	303	303	298	298	313

Rectifier Product Matrix (cont'd)

For Triggering Triacs

RCA Diacs	 DO-15 (Plastic)	
	D3202Y	D3202U
I_{pk}	2A	2A
$V_{(BO)}$	29 min. 35 max. V	25 min. 40 max. V
$\lvert +V_{(BO)}\rvert - \lvert -V_{(BO)}\rvert$	+3 max. V	+3 max. V
$\lvert \Delta V\pm \rvert$	9 min. V	9 min. V
File No.	577	577
Page No.	350	350

ITR Product Matrix

Horizontal - Deflection Circuits

RCA ITR's*		 TO-66	
$I_{T(RMS)}$		TRACE 5A	RETRACE 5A
I_{TSM}		50A	50A
V_{DROM}(V)	400		S3800D
	500	S3800E	
	550		S3800EF
	600		S3800M
	650	S3800MF	
	700		S3800S
	750	S3800SF	
I_{GT}(mA)		40	45
V_{GT}(V)		4	4
File No.		639	639
Page No.		199	199

* Integrated Thyristor/Rectifier

Application Information

Triacs

LOW-CURRENT SENSITIVE-GATE

Current $I_{T(RMS)}$-A	Voltage Range - V	Package	Series	Typical Applications
1.6 - 2.5	100-400	TO-5 & TO-5 w Rad.	T2300 T2310 T2301 T2311 T2302 T2312	IC Control Circuit to Power Control

GENERAL PURPOSE

Current $I_{T(RMS)}$-A	Voltage Range - V	Package	Series	Typical Applications
1.9 - 2.5	100-600	TO-5 & TO-5 w Rad.	2N5757 T2313	General Purpose AC Power Switching ■ Light Control ■ Motor Control—Static & Speed ■ Heat/Comfort Control ■ Solid State Static Switching ■ Three Phase Power Control
6	200-400	TO-220AB (VERSAWATT)	T2500	
3.3 - 6	200-600	TO-66 & TO-66 w Rad.	T2700 T2710	
6 - 8	100-450	TO-220AB (VERSAWATT)	T2800 T2850 T2801	
15	200-600	Press-Fit	2N5572 T4100	
15	200-600	Stud	2N5574 T4110	
15	200-600	Isolated-Stud	T4120	
10	200-600	Press-Fit	2N5568 T4101	
10	200-600	Stud	2N5570 T4111	
10	200-600	Isolated-Stud	T4121	
15	200-600	TO-66	T4700	
40	200-800	Press-Fit	2N5443 T6400	
40	200-800	Stud	2N5446 T6410	
40	200-800	Isolated-Stud	T6420	
30	200-600	Press-Fit	T6401	
30	200-600	Stud	T6411	
30	200-600	Isolated-Stud	T6421	
60	200-600	Press-Fit, Flex. Id	T8401	
60	200-600	Stud Flex. Id	T8411	
60	200-600	Isolated-Stud Flex. Id	T8421	
80	200-600	Press-Fit	T8430	
80	200-600	Stud	T8440	
80	200-600	Isolated-Stud	T8450	

400 Hz

Current $I_{T(RMS)}$-A	Voltage Range - V	Package	Series	Typical Applications
0.5	200-400	TO-5	T2304 T2305	Airborne-Type Equipment and 60-Hz Applications Requiring High Commutating dv/dt ■ Motor Starters
15	200-400	Press-Fit	T4103	
15	200-400	Stud ▲	T4113	
10	200-400	Press-Fit	T4104	
10	200-400	Stud ▲	T4114	
6	200-400	Press-Fit	T4105	
6	200-400	Stud ▲	T4115	
40	200-400	Press-Fit	T6404	
40	200-400	Stud ▲	T6414	
25	200-400	Press-Fit	T6405	
25	200-400	Stud ▲	T6415	

▲ On request, isolated-stud package types are available.

ZERO-VOLTAGE SWITCHING

Triacs in most series are characterized for applications utilizing Zero-Voltage switching with RCA-CA3058, CA3059, and CA3079 IC triggering circuits — see product matrix for types in each series.

For Types not listed, contact your RCA Representative.

SCR's

LOW-CURRENT SENSITIVE-GATE

Current	Voltage Range - V	Package	Series	Typical Applications
4	15-600	TO-220AB (VERSAWATT)	S2060 S2061 S2062	Logic Interface to Power Control

GENERAL PURPOSE PHASE CONTROL

Current	Voltage Range - V	Package	Series	Typical Applications
2	200-600	TO-8	2N4102	Fuel Igniters
4.5	100-600	TO-8	S2400	CD Ignition, "Crowbars"
3.3 - 7	200-600	TO-5, TO-5 w Rad., TO-5 w Spdr.	S2600 S2610 S2620	CD Ignition
1.7 - 5	200-600	TO-66 & TO-66 w Rad.	2N4101 S2710	CD Ignition, Small Motor Control
8	100-400	TO-220AB (VERSAWATT)	S2800	CD Ignition, Regulators, Small Motor Control, and General Purpose
12.5	100-600	TO-3	2N4103	General Purpose
20	100-600	Press-Fit	S6200	
20	100-600	Stud	S2610	
20	100-600	Isolated-Stud	S6220	

Application Information

SCR's (cont'd)

GENERAL PURPOSE PHASE CONTROL

Current $I_{T(RMS)}$-A	Voltage Range - V	Package	Series	Typical Applications
10	100-600	Press-Fit	S6201	General Purpose
10	100-600	Stud	S2611	
10	100-600	Isolated-Stud	S6221	
35	100-800	Press-Fit	2N3873	
35	100-800	Stud	2N3899	
35	100-800	Isolated-Stud	S26420	
25	25-600	TO-48	2N690	
16	25-500	TO-48	2N1850A	

INVERTERS

5	200-600	TO-66	S3700	High-Frequency Power Supplies
5	600	TO-66	S3701	Laser Diode Driver
5	700-750	TO-66	S3702 S3703	110° TV Deflection
5	100-700	TO-66 & TO-66 w Rad.	S3704 S3714	
5	600	TO-66	S3705 S3706	90° TV Deflection
35	600	TO-48	S6431	Pulse Modulators
35	50-600	TO-48	2N3653 2N3658	Inverters, Choppers

ITR's

TV Horizontal Deflection

5	400-750	TO-66	S3800	Commutating and Trace Switches

Rectifiers

STANDARD—Lead-Type Hermetic and Plastic Packages

Current I_O-A	Voltage Range - V	Package	Series	Typical Applications
0.75	100-600	DO-1	1N445B 1N547	General Purpose
1	50-600	DO-1	1N1764A 1N2864A	
1.5	50-1000	Plastic	1N5399 D1201	
0.75	200-800	DO-26	1N3196	
1	200-800	DO-26	1N5214	
0.75	200-1000	DO-26	1N3563	
1	200-800	DO-26	1N5218	

STANDARD—Stud Package

6	50-600	DO-4	1N1348B	General Purpose
12	50-600	DO-4	1N1206A	
20	50-600	DO-5	1N1198A	
40	50-600	DO-5	1N1190A	

FAST-RECOVERY TYPE—Lead-Type Hermetic and Plastic Packages

Current $I_{F(RMS)}$-A	Voltage Range - V	Package	Series	Typical Applications
3	700-750	DO-1	D2102	TV Deflection, Inverters, and High-Frequency Power Supplies
1.5	50-800	DO-15 (Plastic)	D2201	
1.9	50-800	DO-26	D2601	

FAST-RECOVERY TYPE—Stud Package

9	50-600	DO-4	1N3883 D2406	Inverters and High-Frequency Power Supplies
18	50-600	DO-4	1N3893 D2412	
30	50-600	DO-5	1N3903 D2520	
30	50-400	DO-5	1N3913	
60	50-600	DO-5	D2540	

Diacs

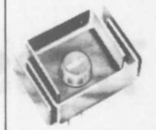
Lead-Type Plastic Package

2 (pk)	25-40 (V_{BO})	DO-15 (Plastic)	D3202	For Triggering Triacs

Triacs

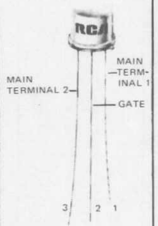
RCA
Solid State
Division

Thyristors
2N5754 2N5756
2N5755 2N5757
T2313 Series



T2313 Series

H-1468



2N5754
2N5755
2N5756
2N5757

H-1380V1

2.5-Ampere Silicon Triacs

For Low-Power Phase-Control and Load-Switching Applications

For Low-Voltage Operation – 2N5754, T2313A (40684)■
For 120-V Line Operation – 2N5755, T2313B (40685)■
For 240-V Line Operation – 2N5756, T2313D (40686)■
For High-Voltage Operation – 2N5757, T2313M (40687)■

■Numbers in parentheses (e.g. 40684) are former RCA type numbers.

Features:

- 25/40 mA I_{GT}
- Shorted Emitter Design
- 3-Lead Package for Printed Circuit Board Applications
- Small Size . . . Suitable for Remote Switching Applications

These RCA triacs are gate-controlled full-wave silicon ac switches that are designed to switch from an off-state to an on-state for either polarity of applied voltage with positive or negative gate triggering voltages.

The gate sensitivity of these triacs permits the use of economical transistorized control circuits and enhances their use in low-power phase control and load-switching applications.

Types 2N5754, 2N5755, 2N5756, 2N5757★ utilize a compact package (similar to JEDEC TO-5) and have an RMS on-state current rating of 2.5 A and repetitive peak off-state voltage ratings of 100, 200, 400, and 600 volts, respectively.

Types T2313A, T2313B, T2313D, T2313M▲ are the same as the 2N5754, 2N5755, 2N5756, 2N5757, respectively but have factory-attached heat-radiators and are intended for printed-circuit board applications.

★Formerly RCA Dev. types TA7500, TA7501, TA7502, and TA7503, respectively.

▲Formerly RCA Dev. types TA7579, TA7580, TA7581, and TA7582, respectively.

MAXIMUM RATINGS, ***Absolute-Maximum Values:***
For Operation with 50/60-Hz, Sinusoidal Supply Voltage and Resistive or Inductive Load

* REPETITIVE PEAK OFF-STATE VOLTAGE●	V_{DROM}		
Gate Open, T_J = 65°C to 100°C			
2N5754, T2313A		100	V
2N5755, T2313B		200	V
2N5756, T2313D		400	V
2N5757, T2313M		600	V
RMS ON-STATE CURRENT	$I_{T(RMS)}$		
Conduction angle = 360°:			
* Case temperature (T_C) = 70°C			
2N5754, 2N5755, 2N5756, 2N5757		2.5	A
Ambient temperature (T_A) = 25°C			
T2313 series		1.9	A
For other conditions		See Figs. 2,3,4, & 5.	
PEAK SURGE (NON-REPETITIVE) ON-STATE CURRENT	I_{TSM}		
* For one full cycle of applied principal voltage (60-Hz, sinusoidal)		25	A
For one full cycle of applied principal voltage (50-Hz, sinusoidal)		21	A
For more than one full cycle of applied voltage		*See Fig.6.*	
* PEAK GATE-TRIGGER CURRENT	I_{GTM}		
For 1 μs 1 max		1	A
GATE POWER DISSIPATION:			
* PEAK†	P_{GM}		
For 1 μs max		10	W
AVERAGE	$P_{G(AV)}$		
* For case temperature (T_C) = 60°C		0.15	W
* For ambient temperature (T_A) = 25°C		0.05	W
* TEMPERATURE RANGE‡:			
Storage		-65 to 150	°C
Operating (case)		-65 to 100	°C
* LEAD TEMPERATURE:			
During soldering, terminal temperature at a distance ≥ 1/16 in. (1.58 mm) from the case for 10 s		225	°C

● For either polarity of main terminal 2 voltage (V_{MT2}) with reference to main terminal 1.

† For either polarity of gate voltage (V_G) with reference to main terminal 1.

‡ For information on the reference point of temperature measurement, see *Dimensional Outlines*.

* In accordance with JEDEC registration data format (JS-14, RDF-2).

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ELECTRICAL CHARACTERISTICS

At Maximum Ratings and at Indicated Case Temperature (T_C) Unless Otherwise Specified

CHARACTERISTIC	Mode	V_{MT2}	V_G	SYMBOL	LIMITS ALL TYPES Min.	Typ.	Max.	UNITS
* **Peak Off-State Current:** ♦								
Gate Open, T_J = 100°C and V_{DROM} = Max. rated value				I_{DROM}	-	0.2	0.75	mA
Maximum On-State Voltage: ♦				V_{TM}				V
For i_T = 10 A (peak) and T_C = 25°C					-	2.2	2.6	
* For i_T = 3.5 A (peak) and T_C = 25°C					-	-	1.8	
DC Holding Current: ♦				I_{HO}				mA
Gate Open, Initial principal current = 150 mA (DC), V_D = 12 V								
At T_C = 25°C					-	6	35	
At T_C = -65°C					-	20	82 *	
For other case temperatures					← See Fig.8. →			
* **Critical Rate-of-Rise of Off-State Voltage:** ♦				dv/dt				V/μs
For V_D = V_{DROM}, exponential voltage rise, and gate open, T_C = 100°C					10	100	-	
DC Gate-Trigger Current: ♦ †				I_{GT}				mA
For V_D = 12 V (DC), R_L = 30Ω, and T_C = 25°C	I^+	positive	positive		-	5	25	
	III^-	negative	negative		-	5	25	
	I^-	positive	negative		-	10	40	
	III^+	negative	positive		-	10	40	
T_C = -65°C	I^+	positive	positive		-	30	60 *	
	III^-	negative	negative		-	30	60 *	
	I^-	positive	negative		-	40	100 *	
	III^+	negative	positive		-	40	100 *	
For other case temperatures					← See Fig.11. →			
DC Gate-Trigger Voltage: ♦ †				V_{GT}				V
For V_D = 12 V (DC) and R_L = 30 Ω								
At T_C = 25°C					-	0.9	2.2	
At T_C = -65°C					-	1.5	3*	
For other case temperatures					← See Fig.12. →			
* For v_D = V_{DROM} and R_L = 125Ω								
At T_C = 100°C					0.2	-	-	
* **Thermal Resistance, Junction-to-Case:**								
Steady-State				θ_{J-C}	-	-	8.5	°C/W

♦ For either polarity of main terminal 2 voltage (V_{MT2}) with reference to main terminal 1.

* In accordance with JEDEC registration data format (JS-14, RDF-2).

† For either polarity of gate voltage (V_G) with reference to main terminal 1.

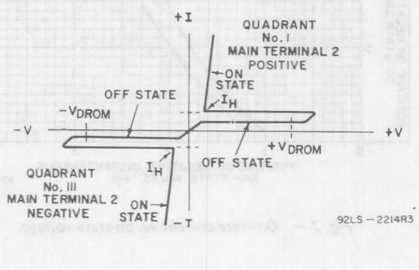


Fig. 1 — Principal voltage-current characteristic.

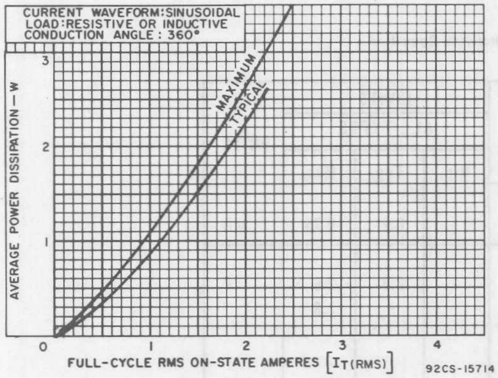


Fig. 2 — Power dissipation vs. on-state current.

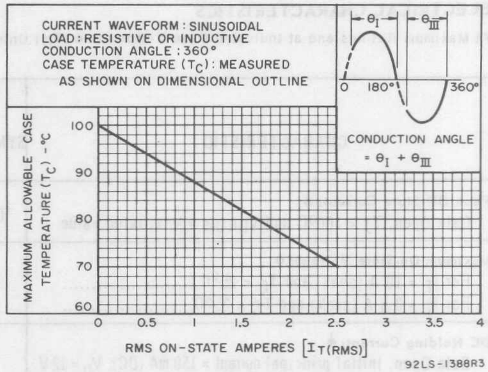


Fig. 3 — Maximum allowable case temperature vs. on-state current.

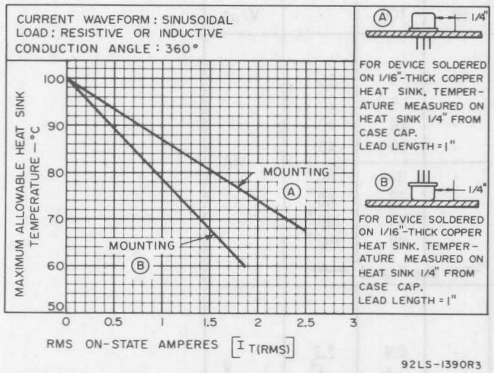


Fig. 4 — Maximum allowable heat-sink temperature vs. on-state current.

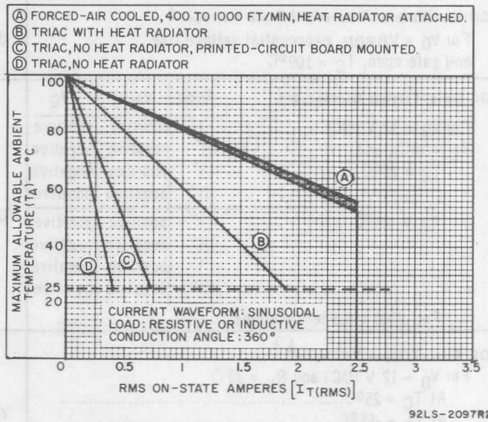


Fig. 5 — Maximum allowable ambient temperature vs. on-state current.

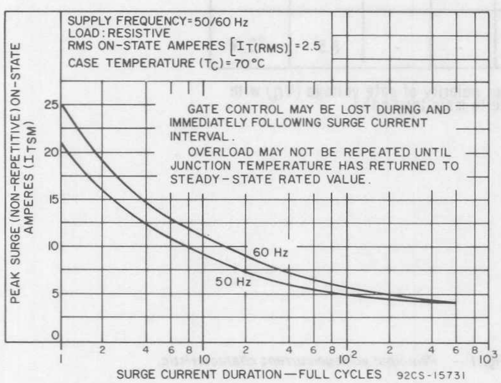


Fig. 6 — Peak surge on-state current vs. surge-current duration.

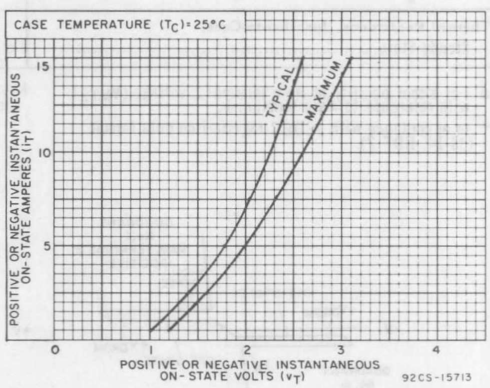


Fig. 7 — On-state current vs. on-state voltage.

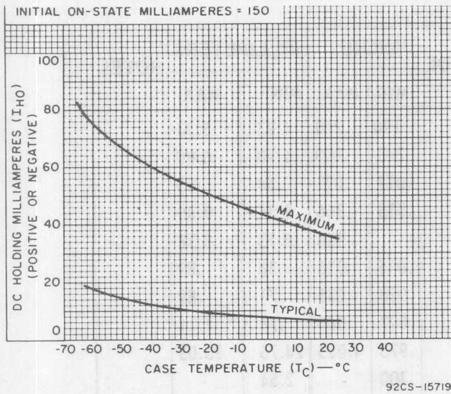


Fig. 8 — DC holding current (positive or negative) vs. case temperature.

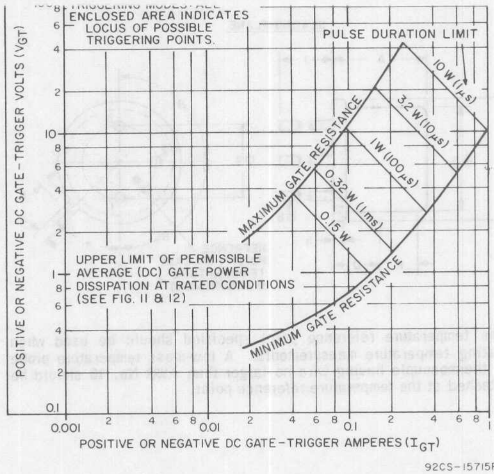
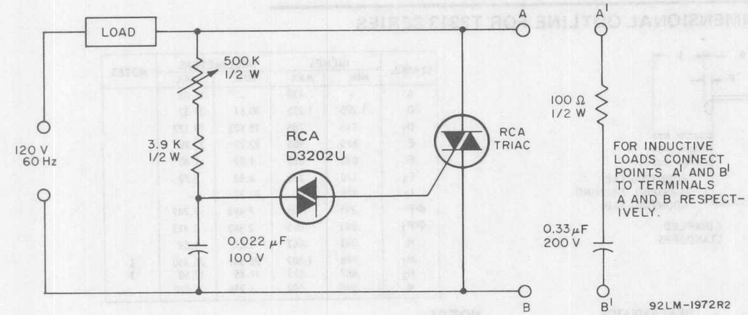


Fig. 9 — Gate trigger characteristics and limiting conditions for determination of permissible gate trigger pulses.



NOTE: For incandescent lamp loads which produce burnout current surges with I^2t values greater than 2.5 ampere^2 seconds, connect a 10-ohm resistor of appropriate power rating in series with the load. This rating can be determined as follows:

Power Rating of 10-ohm Resistor = 10(rms load current)^2

Fig. 10 — Typical phase-control circuit.

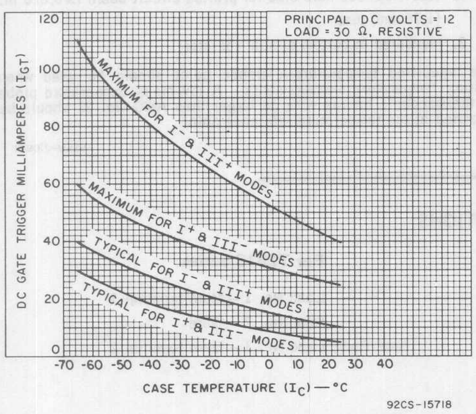


Fig. 11 — DC gate-trigger current vs. case temperature.

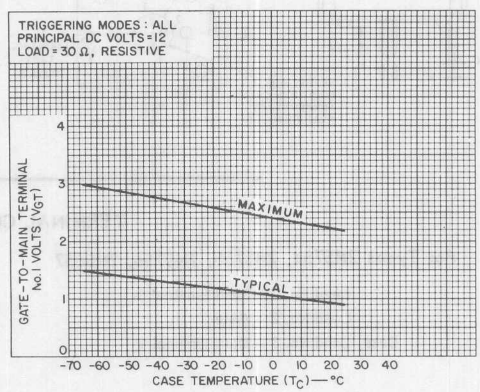
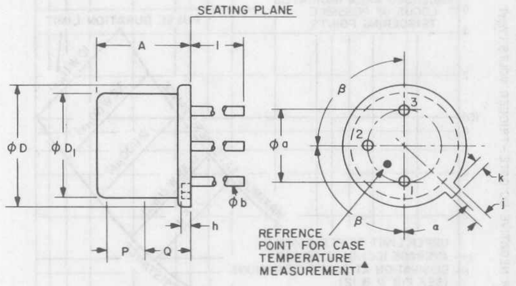


Fig. 12 — DC gate-trigger voltage vs. case temperature.

DIMENSIONAL OUTLINE FOR TYPES 2N5754, 2N5755, 2N5756, 2N5757



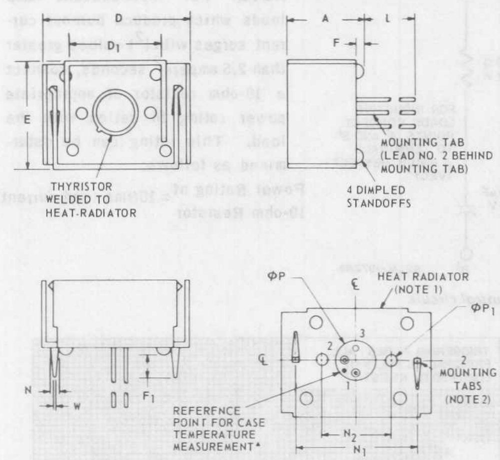
▲The temperature reference point specified should be used when making temperature measurements. A low-mass temperature probe or thermocouple having wire no larger than AWG No. 16 should be attached at the temperature reference point.

SYMBOL	INCHES		MILLIMETERS		NOTES
	MIN.	MAX.	MIN.	MAX.	
ϕa	.190	.210	4.83	5.33	
A	.240	.260	6.10	6.60	
ϕb	.017	.021	.44	.53	
ϕD	.335	.366	8.51	9.30	
ϕD_1		.330	8.13	8.38	
h	.015	.035	.38	.89	
i	.028	.035	.71	.89	
k	.029	.045	.74	1.14	
l	.975	1.025	24.76	26.03	
P	.100	-	2.54	-	
Q	-	-	-	-	1
α	45° NOMINAL				
β	50° NOMINAL				

Note 1: Details of outline in this zone optional.

92LM-2048R2

DIMENSIONAL OUTLINE FOR T2313 SERIES



SYMBOL	INCHES		MILLIMETERS		NOTES
	MIN.	MAX.	MIN.	MAX.	
A	–	.630	–	16.00	
D	1.205	1.235	30.61	31.37	
D_1	.745	.755	18.923	19.177	
E	.875	.905	22.22	22.99	
F	.040	.055	1.02	1.40	
F_1	.170	.225	4.32	5.72	
L	.920	–	23.37	–	
ΦP	.295	.305	7.493	7.747	
ΦP_1	.093	.095	2.362	2.413	
N	.048	.062	1.21	1.57	
N_1	.998	1.002	25.349	25.450	3
N_2	.687	.689	17.45	17.50	3
W	.048	.052	1.219	1.320	

NOTES:
1. 0.035 C.R.S., finish: electroless nickel plate
2. Recommended hole size for printed-circuit board is 0.070 in. (1.78 mm) dia.
3. Measured at bottom of heat radiator

▲The specified temperature-reference point should be used when making temperature measurements. A low-mass temperature probe or thermocouple having wire no larger than AWG No. 26 should be attached at the temperature reference point.

92LM-2109R1

TERMINAL CONNECTIONS

For Types 2N5754, 2N5755, 2N5756, 2N5657

Lead No. 1 – Main terminal 1
Lead No. 2 – Gate
Case, Lead No. 3 – Main terminal 2

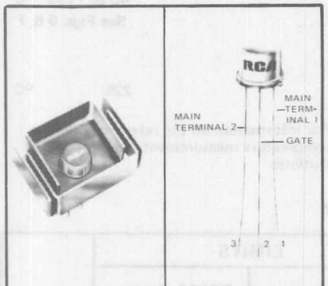
For T2313 Series

Lead No. 1 – Main terminal 1
Lead No. 2 – Gate
Heat Rad., Lead No. 3 – Main terminal 2

RCA
Solid State
Division

Thyristors

T2300 T2302 T2310 T2312 Series



T2310 Series
T2312 Series
H-1468

T2300 Series
T2302 Series
H-1380V1

2.5-Ampere Sensitive-Gate Silicon Triacs

For Low-Power Phase-Control and Load-Switching Applications

For Low-Voltage Operation – T2300A, T2302A, T2310A, T2312A (40525, 40528, 40531, 40534)*

For 120-V Line Operation – T2300B, T2302B, T2310B, T2312B (40526, 40529, 40532, 40535)*

For 240-V Line Operation – T2300D, T2302D, T2310D, T2312D (40527, 40530, 40533, 40536)*

*Numbers in parentheses (e.g. 40525) are former RCA type numbers.

Features:

- **Very High Gate Sensitivity**
  3 mA max. for T2300 and T2310 series
  10 mA max. for T2302 and T2312 series
- **3-Lead Package for Printed Circuit Board Applications**
- **Shorted Emitter Design**

RCA T2300-, T2302-, T2310-, and T2312-series triacs are gate-controlled full-wave ac silicon switches. They are designed to switch from a blocking state to a conducting state for either polarity of applied voltage with positive or negative gate triggering.

The T2302 series has higher dv/dt capability and higher gate trigger current requirements than the T2300 series. The gate sensitivity of these triacs permits the use of economical transistorized and IC control circuits and enhances their use in low-power phase control and load-switching applications.

The T2300 series has rms on-state current ratings of 2.5 amperes at a case temperature of +60°C while the T2302 series has the same ratings at a case temperature of +70°C.

The repetitive peak off-state voltage rating for T2300A and T2302A is 100 volts; for T2300B and T2302B, 200 volts; and for T2300D and T2302D, 400 volts.

The T2310 and T2312 series are the same as the T2300 and T2302 series, respectively, but have factory-attached heat-radiators and are intended for printed-circuit-board applications.

MAXIMUM RATINGS, *Absolute-Maximum Values:*
For Operation with 50/60-Hz, Sinuosidal Supply Voltage and Resistive or Inductive Load

REPETITIVE PEAK OFF-STATE VOLTAGE♦ (Gate Open):	V_{DROM}		
T_J = -40° C to +90° C: T2300A, T2310A		100	V
T2300B, T2310B		200	V
T2300D, T2310D		400	V
T_J = -40° C to +100°C: T2302A, T2312A		100	V
T2302B, T2312B		200	V
T2302D, T2312D		400	V
RMS ON-STATE CURRENT (Conduction Angle = 360°):	$I_{T (RMS)}$		
T_C = 60° C: T2300 series		2.5	A
T_C = 70° C: T2302 series		2.5	A
T_A = 25° C: T2300 series		0.35	A
T2302 series		0.40	A
For other conditions		See Figs. 2, 3, 4 & 5	
For heat-radiator types		See Figs. 6 & 7	
PEAK SURGE (NON-REPETITIVE) ON-STATE CURRENT:	I_{TSM}		
For one full cycle of applied principal voltage			
60 Hz sinusoidal		25	A
50 Hz sinusoidal		21	A
For more than on full cycle of applied voltage		See Fig. 8	
PEAK GATE-TRIGGER CURRENT‡:	I_{GTM}		
For 1 μs max		0.5	A

MAXIMUM RATINGS (Cont'd)

GATE POWER DISSIPATION†:

Peak (For 1 μs max.)	P_{GM}	10	W
Average: T_C = 60° C	$P_{G\ (AV)}$	0.15	W
T_A = 25° C		0.05	W

TEMPERATURE RANGE‡:

Storage	-40 to +150	°C
Operating (case): 40525, 40526, 40527	-40 to +90	°C
40528, 40529, 40530	-40 to +100	°C
Heat-radiator types (From -40° C) Upper limits	See Figs. 6 & 7	

LEAD TEMPERATURE:

During soldering, terminal temperature at a distance ≥ 1/16 in. (1.58 mm) from the case for 10 s	225	°C

♠ For either polarity of main terminal 2 voltage (V_{MT2}) with reference to main terminal 1.

† For either polarity of gate voltage (V_G) with reference to main terminal 1.

‡ For information on the reference point of temperature measurement see *Dimensional Outlines.*

ELECTRICAL CHARACTERISTICS

At Maximum Ratings and at Indicated Case Temperature (T_C) Unless Otherwise Specified

CHARACTERISTIC	SYMBOL	LIMITS T2300 Series T2310 Series MIN.	TYP.	MAX.	LIMITS T2302 Series T2312 Series MIN.	TYP.	MAX	UNITS
Peak Off-State Current:♠ Gate Open and V_{DROM} = Max. rated value								
At T_j = +100° C	I_{DROM}	–	–	–	–	0.2	0.75	mA
At T_j = +90° C		–	0.2	0.75	–	–	–	
Maximum On-State Voltage:♠ For i_T = 10 A (peak) and T_C = 25° C	V_{TM}	–	1.7	2.2	–	1.7	2.2	V
DC Holding Current:♠ Gate Open, Initial principal current = 150 mA (DC), V_D = 12								
At T_C = 25° C	I_{HO}	–	2	5	–	6.5	15	mA
For other case temperatures			See Fig. 14			See Fig. 15		
Critical Rate-of-Rise of Off-State Voltage:♠ For V_D = V_{DROM}, exponential voltage rise, and gate open	dv/dt							V/μs
At T_C = +100° C		–	–	–	–	10	–	
At T_C = +90° C		–	5	–	–	–	–	
DC Gate-Trigger Current:♠† For V_D = 12 V (DC), R_L = 30 Ω, and T_C = 25° C — Mode 1+, V_{MT2} positive, V_G positive	I_{GT}	–	1	3	–	3.5	10	mA
Mode 111−, V_{MT2} negative, V_G negative		–	1	3	–	3.5	10	
Mode 1−, V_{MT2} positive, V_G negative		–	2	3	–	7	10	
Mode 111+, V_{MT2} negative, V_G positive		–	2	3	–	7	10	
For other case temperatures			See Fig. 12			See Fig. 13		
DC Gate-Trigger Voltage:♠† For V_D = 12 V (DC) and R_L = 30 Ω								
At T_C = 25° C	V_{GT}	–	1	2.2	–	1	2.2	V
For other case temperatures			See Fig. 11			See Fig. 11		
For v_D = V_{DROM} and R_L = 125 Ω								
At T_C = 100° C		–	–	–	0.15	–	–	
At T_C = +90° C		0.15	–	–	–	–	–	
Thermal Resistance, Junction-to-Case: Steady-State	$R_{\theta JC}$		8.5 (max.) (T2300 series)			8.5 (max.) (T2302 series)		°C/W

♠ For either polarity of main terminal 2 voltage (V_{MT2}) with reference to main terminal 1.

† For either polarity of gate voltage (V_G) with reference to main terminal 1.

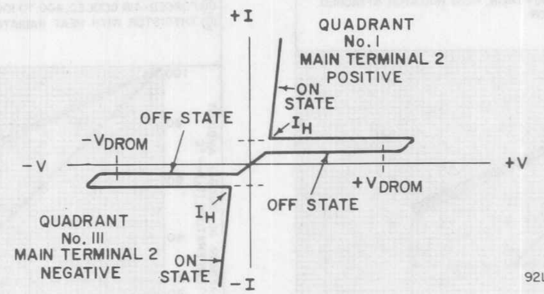


Fig. 1 — Principal voltage-current characteristics.

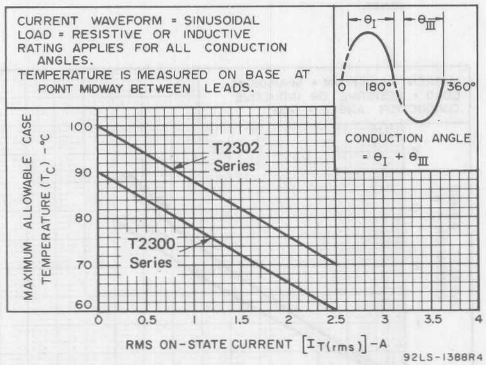


Fig. 2 — Conduction rating chart (case temperature) for T2300 and T2302 series.

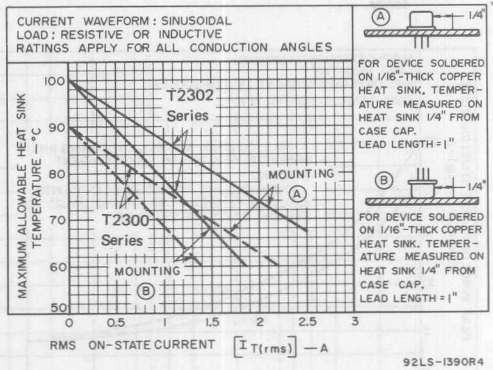


Fig. 3 — Conduction characteristics as a function of mounting method for T2300 and T2302 series.

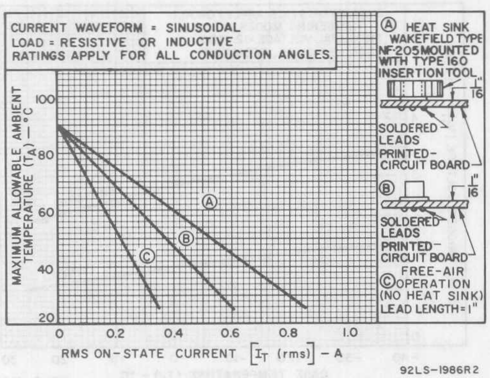


Fig. 4 — Conduction rating chart (ambient temperature) for T2300 series.

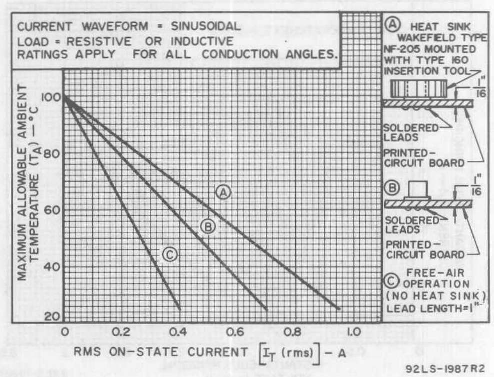


Fig. 5 — Conduction rating chart (ambient temperature) for T2302 series.

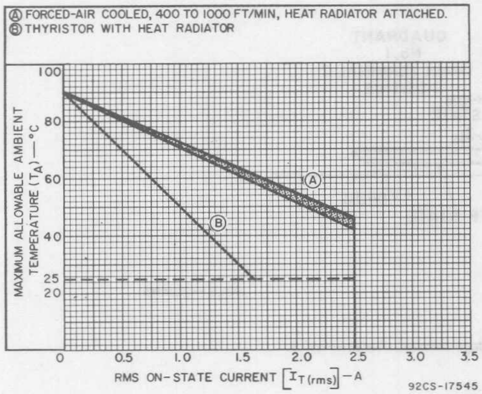


Fig. 6 — Conduction rating chart (ambient temperature) for T2310 series.

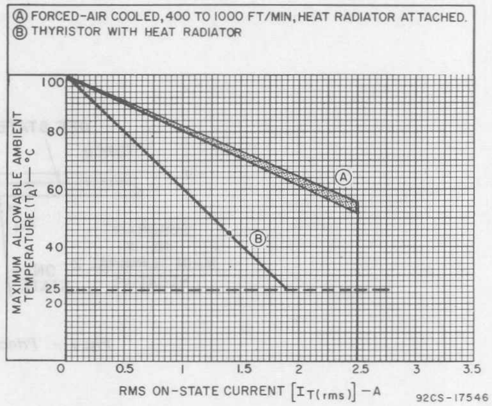


Fig. 7 — Conduction rating chart (ambient temperature) for T2312 series.

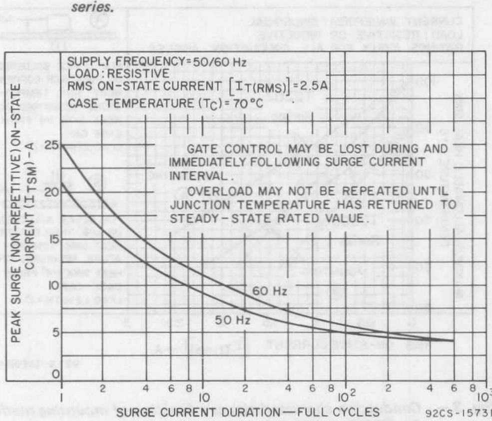


Fig. 8 — Peak surge on-state current vs. surge-current duration for all types.

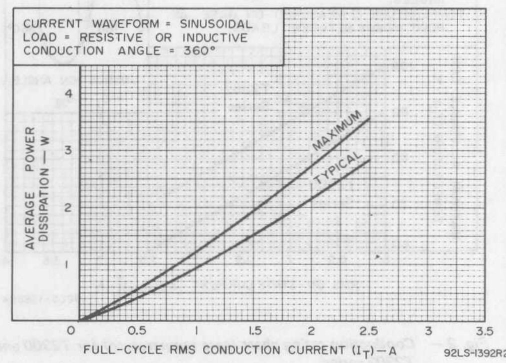


Fig. 9 — Power dissipation curves for all types.

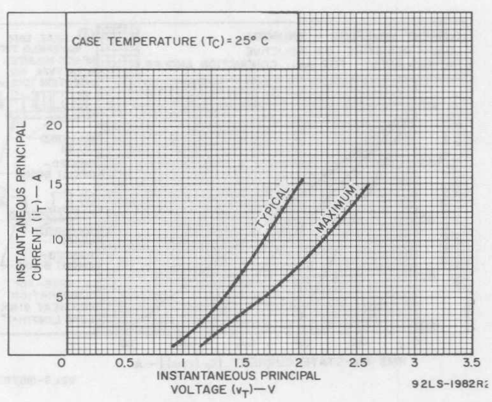


Fig. 10 — On-state characteristics for either direction of principal current for all types.

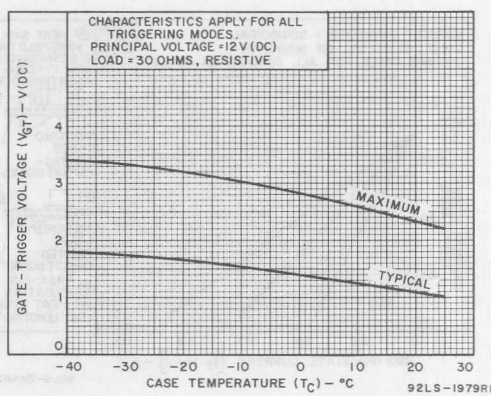


Fig. 11 — DC Gate-trigger voltage characteristics for all types.

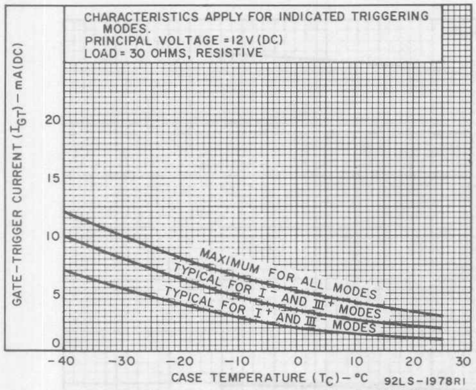


Fig. 12 – DC gate-trigger current characteristics for T2300 and T2310 series.

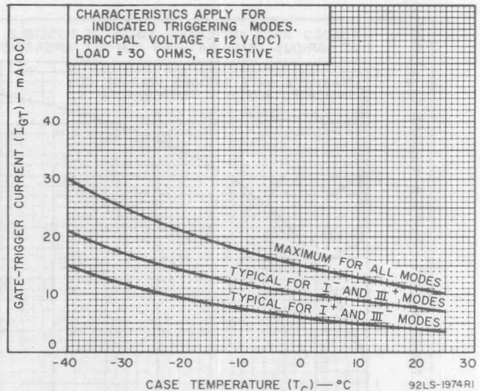


Fig. 13 – DC gate-trigger current characteristics for T2302 and T2312 series.

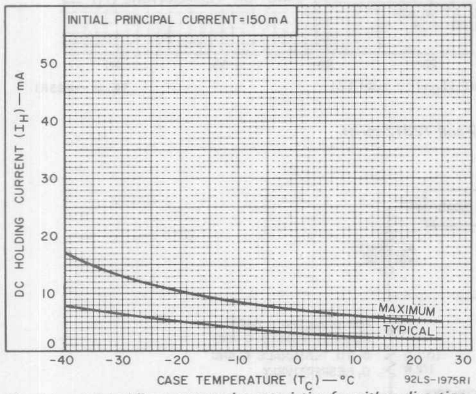


Fig. 14 – DC holding current characteristics for either direction of principal current for T2300 and T2310 series.

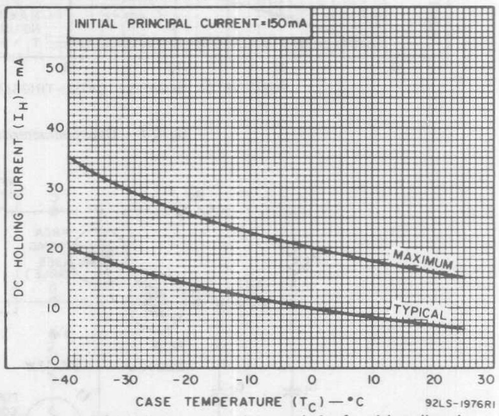


Fig. 15 – DC holding current characteristics for either direction of prinicpal current for T2302 and T2312 series.

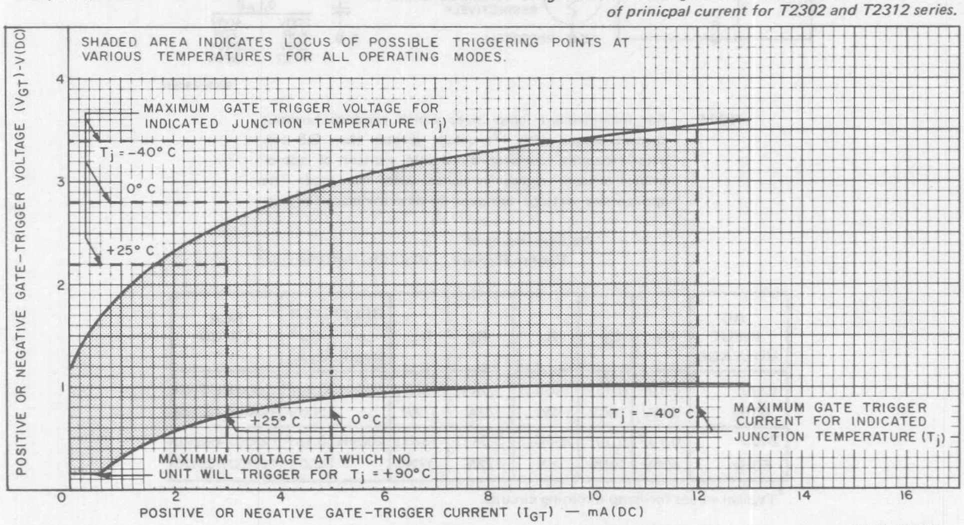


Fig. 16 – Gate characteristics for T2300 and T2310 series.

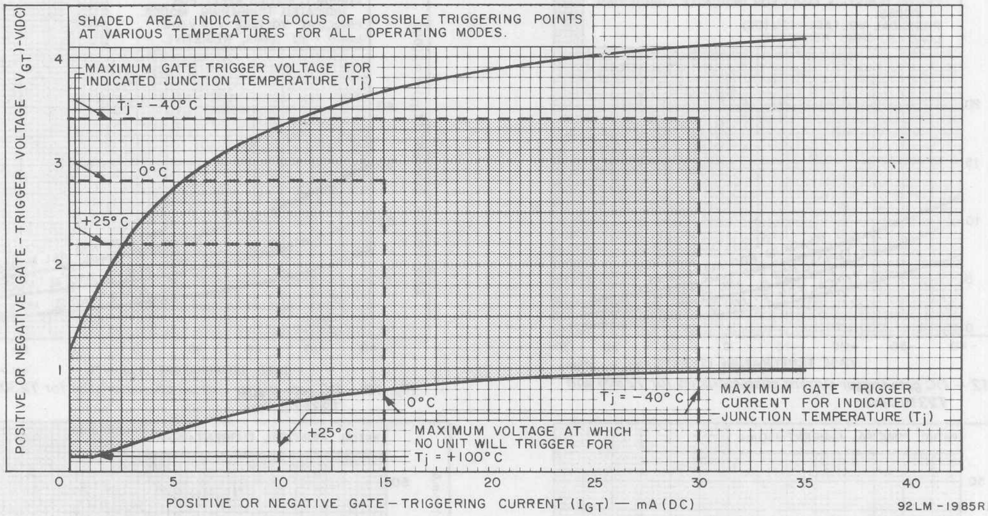
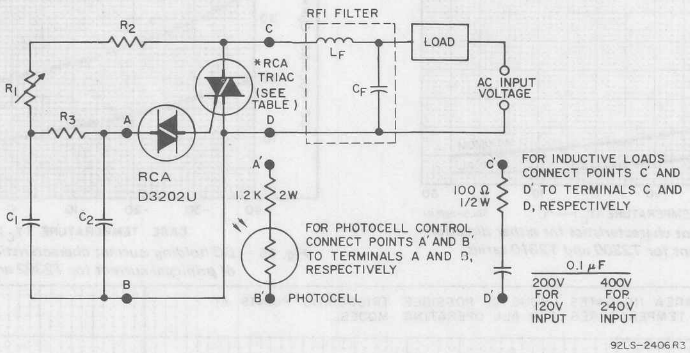


Fig. 17 — Gate characteristics for T2302 and T2312 series.



NOTE: For incandescent lamp loads which produce burnout current surges with I^2t values greater than 2.5 ampere^2 seconds, connect a 10-ohm resistor of appropriate wattage rating in series with the load. The appropriate wattage rating can be determined as follows:

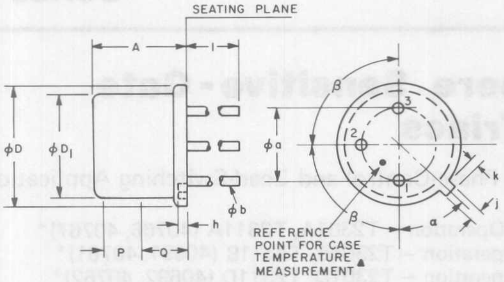
$$\text{Wattage Rating of 10-ohm Resistor} = 10 \times (\text{rms load current})^2$$

AC INPUT VOLTAGE	C_1	C_2	R_1	R_2	R_3	RFI FILTER L_F* (typ.)	RFI FILTER C_F* (typ.)	RCA TYPES
120V 60Hz	0.1μF 200V	0.1μF 100V	100KΩ 1/2W	2.2KΩ 1/2W	15KΩ 1/2W	100μH	0.1μF 200V	T2300B,T2310B T2302B,T2312B
240V 50Hz	0.1μF 400V	0.1μF 100V	250KΩ 1W	3.3KΩ 1/2W	15KΩ 1/2W	200μH	0.1μF 400V	T2300D,T2302D T2310D,T2312D

*Typical values for lamp dimming circuits.

Fig. 18 — Typical phase-control circuit for lamp dimming, heat controls, and universal motor speed controls.

DIMENSIONAL OUTLINE FOR T2300 AND T2302 SERIES



SYMBOL	INCHES		MILLIMETERS		NOTES
	MIN.	MAX.	MIN.	MAX.	
ϕa	0.190	0.210	4.83	5.33	
A	0.240	0.260	6.10	6.60	
ϕb	0.017	0.021	0.44	0.53	
ϕD	0.335	0.366	8.51	9.30	
ϕD_1		0.330	8.13	8.38	
h	0.015	0.035	0.38	0.89	
i	0.028	0.035	0.71	0.89	
k	0.029	0.045	0.74	1.14	
L	0.975	1.025	24.76	26.03	
P	0.100	-	2.54		
Q	-	-	-	-	1
α	45° NOMINAL				
β	50° NOMINAL				

▲The temperature reference point specified should be used when making temperature measurements. A low-mass temperature probe or thermocouple having wire no larger than AWG No. 16 should be attached at the temperature reference point.

Note 1: Details of outline in this zone optional.

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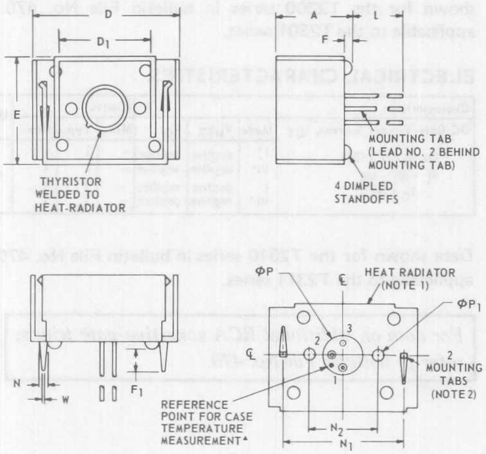
DIMENSIONAL OUTLINE FOR T2310 AND T2312 SERIES



SYMBOL	INCHES		MILLIMETERS		NOTES
	MIN.	MAX.	MIN.	MAX.	
A	–	0.630	–	16.00	
D	1.205	1.235	30.61	31.37	
D_1	0.775	0.785	19.69	19.93	
E	0.875	0.905	22.22	22.99	
F	0.040	0.055	1.02	1.40	
F_1	0.160	0.195	4.06	4.94	
L	0.920	–	23.37	–	
ϕP	0.295	0.305	7.493	7.747	
ϕP_1	0.093	0.095	2.362	2.413	
N	0.048	0.062	1.21	1.57	
N_1	0.998	1.002	25.349	25.450	3
N_2	0.687	0.689	17.45	17.50	3
W	0.048	0.052	1.219	1.320	

NOTES:

1. 0.035 C.R.S., finish: electroless nickel plate
2. Recommended hole size for printed-circuit board is 0.070 in. (1.78 mm) dia.
3. Measured at bottom of heat-radiator

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▲The specified temperature-reference point should be used when making temperature measurements. A low-mass temperature probe or thermocouple having wire no larger than AWG No. 26 should be attached at the temperature reference point.

TERMINAL CONNECTIONS

For T2300 and T2302 series

Lead No. 1 – Main terminal 1
Lead No. 2 – Gate
Case, Lead No. 3 – Main terminal 2

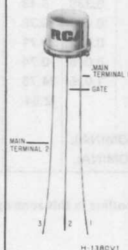
For T2310 and T2312 series

Lead No. 1 – Main terminal 1
Lead No. 2 – Gate
Heat Rad., Lead No. 3 – Main terminal 2

RCA
Solid State Division

Thyristors
T2301 T2311 Series

T2311 Series



T2301 Series

2.5-Ampere Sensitive-Gate Silicon Triacs

For Low-Power Phase-Control and Load-Switching Applications

For Low-Voltage Operation – T2301A, T2311A (40766, 40767)*
For 120-V Line Operation – T2301B, T2311B (40691, 40761)*
For 240-V Line Operation – T2301D, T2311D (40692, 40762)*

*Numbers in parentheses (e.g. 40766) are former RCA type numbers.

Features:

- **Very High Gate Sensitivity – 4 mA**
- **Shorted Emitter Design**
- **Heat-Radiator Package for Printed Circuit Board Applications**
- **Small Size – Suitable for Remote Switching Applications**

RCA T2301- and T2311-series triacs are gate-controlled full-wave ac switches. These devices are designed to switch from an off-state to an on-state for either polarity of applied voltage with positive or negative gate triggering voltages.

The high gate sensitivity of these triacs permits the use of economical transistorized or integrated control circuits and enhances their use in low-power phase control and load-switching applications.

The T2301-series triacs are supplied in a compact package (similar to JEDEC TO-5) and have an RMS on-state current rating of 2.5 A and repetitive peak off-state voltage ratings of 100, 200, and 400 volts.

The T2311-series triacs are the same as the T2301-series triacs, but have factory-attached heat-radiators and are intended for printed-circuit board applications.

With the exception of the characteristics listed below, data shown for the T2300 series in bulletin File No. 470 are applicable to the T2301 series.

ELECTRICAL CHARACTERISTICS:

Characteristic				Limits			Units
DC Gate-Trigger Current, I_{GT}	Mode	V_{MT2}	V_G	Min.	Typ.	Max.	
For v_D = 12 V (DC), R_L = 30 Ω, and T_C = 25° C	I^+	positive	positive	–	1	4	mA
	III^-	negative	negative	–	1	4	mA
	I^-	positive	negative	–	2	4	mA
	III^+	negative	positive	–	2	4	mA

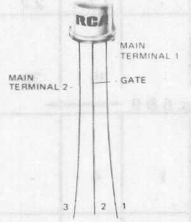
Data shown for the T2310 series in bulletin File No. 470 are applicable to the T2311 series.

For data on additional RCA sensitive-gate triacs, refer to bulletin File No. 470.

11-73

RCA Solid State Division

Thyristors
T2304 T2305 Series



Modified JEDEC TO-5

H 1380V1

400-Hz, 0.5-A Sensitive-Gate Silicon Triacs

For Control-Systems Application in Airborne and Ground-Support Type Equipment

For 115-V Line Operation – T2304B, T2305B (40769, 40771)**
For 208-V Line Operation – T2304D, T2305D (40770, 40772)**

**Numbers in parentheses (e.g. 40769) are former RCA type numbers.

Features:

- High Gate Sensitivity, I_{GT} = 10/40 mA max.
- di/dt Capability = 100 A/μs
- Commutating dv/dt Capability Characterized at 400 Hz
- Shorted-Emitter Design

RCA T2304- and T2305-series triacs are gate-controlled full-wave silicon ac switches. They are designed to switch from an off-state to an on-state for either polarity of applied voltage with positive or negative gate triggering voltages.

These triacs are intended for operation up to 400 Hz with resistive or inductive loads and nominal line voltages of 115 and 208 V RMS sine wave and repetitive peak off-stage voltages of 200 V and 400 V.

The high gate sensitivity of these triacs permits the use of economical transistorized or integrated control circuits and enhances their use in low-power phase control and load-switching applications.

MAXIMUM RATINGS, *Absolute-Maximum Values:*

For Operation with Sinusoidal Supply Voltage at Frequencies up to 400 Hz and with Resistive or Inductive Load.

		T2304B T2305B	T2304D T2305D	
REPETITIVE PEAK OFF-STATE VOLTAGE:*				
Gate open, T_J = -50 to 100°C	V_{DROM}	200	400	V
RMS ON-STATE CURRENT (Conduction angle = 360°):	$I_{T(RMS)}$			
Case temperature (T_C) = 90°C		0.5		A
Ambient temperature (T_A) = 25°C, without heat sink		0.4		A
For other conditions		*See Figs. 3 & 4*		
PEAK SURGE (NON-REPETITIVE) ON-STATE CURRENT:	I_{TSM}			
For one cycle of applied principal voltage				
400 Hz (sinusoidal)		50		A
60 Hz (sinusoidal)		25		A
For more than one cycle of applied principal voltage		*See Fig. 5*		
RATE-OF-CHANGE OF ON-STATE CURRENT:	di/dt			
$V_{DM} = V_{DROM}$, I_{GT} = 60 mA, t_r = 0.1 μs *(See Fig. 14)*		100		A/μs
PEAK GATE-TRIGGER CURRENT:■	I_{GTM}			
For 1 μs (max.) *(See Fig. 10)*		1		A
GATE POWER DISSIPATION:				
PEAK (For 1 μs max., *(See Fig. 10)*	P_{GM}	10		W
AVERAGE (At T_C = 60°C)	$P_{G(AV)}$	0.15		W
(At T_A = 25°C, without heat sink)	$P_{G(AV)}$	0.05		W
TEMPERATURE RANGE:▲				
Storage	T_{stg}	-50 to 150		°C
Operating (Case)	T_C	-50 to 100		°C
LEAD TEMPERATURE (During soldering):				
At distances ≥ 1/16 in. (1.58 mm) from the case for 10 s max.	T_L	225		°C

* For either polarity of main terminal 2 voltage (V_{MT2}) with reference to main terminal 1.
■ For either polarity of gate voltage (V_G) with reference to main terminal 1.
▲ For temperature measurement reference point, see Dimensional Outline.

ELECTRICAL CHARACTERISTICS

At Maximum Ratings and at Indicated Case Temperature (T_C) Unless Otherwise Specified

CHARACTERISTIC	SYMBOL	LIMITS T2304 Series Min.	T2304 Series Typ.	T2304 Series Max.	LIMITS T2305 Series Min.	T2305 Series Typ.	T2305 Series Max.	UNITS
Peak Off-State Current:♠ Gate open, $T_J = 100^oC$, V_{DROM} = Max. rated value	I_{DROM}	-	0.2	0.75	-	0.2	0.75	mA
Maximum On-State Voltage:♠ For i_T = 10 A (peak), $T_C = 25^oC$	V_{TM}	-	1.7	2.2	-	1.7	2.2	V
DC Holding Current:♠ Gate open, Initial principal current = 150 mA (DC), v_D = 12 V, $T_C = 25^oC$	I_{HO}	-	7	15	-	15	30	mA
For other case temperatures		← See Figs. 8 & 9 →						
Critical Rate-of-Rise of Commutation Voltage:♠ For $v_D = V_{DROM}$, $I_{T(RMS)}$ = 0.5 A, commutating di/dt = 1.8 A/ms, gate unenergized, $T_C = 90^oC$ (See Fig. 15)	dv/dt	1	4	-	1	4	-	V/μs
Critical Rate-of-Rise of Off-Stage Voltage:♠ For $v_D = V_{DROM}$, exponentail voltage rise, gate open, $T_C = 100^oC$	dv/dt	10	100	-	10	100	-	V/μs
DC Gate-Trigger Current:♠ (Mode / V_{MT2} / V_G) For v_D = 12 V (DC), $R_L = 30\ \Omega$, $T_C = 25^oC$: I^+ / positive / positive	I_{GT}	-	3.5	10	-	5	25	mA
III^- / negative / negative		-	3.5	10	-	5	25	mA
I^- / positive / negative		-	7	10	-	10	40	mA
III^+ / negative / positive		-	7	10	-	10	40	mA
For other case temperatures		← See Figs. 11 & 12 →						
DC Gate-Trigger Voltage:♠† For v_D = 12 V (DC), $R_L = 30\Omega$, $T_C = 25^oC$	V_{GT}	-	1	2.2	-	1	2.2	V
For other case temperatures		← See Fig. 13 →						
For $v_D = V_{DROM}$, $R_L = 125\Omega$, $T_C = 100^oC$		0.15	-	-	0.15	-	-	V
Gate-Controlled Turn-On Time: (Delay Time + Rise Time) For $v_D = V_{DROM}$, I_{GT} = 60 mA, t_r = 0.1 μs, i_T = 10 A (peak), $T_C = 25^oC$ (See Fig. 16)	t_{gt}	-	1.8	-	2.5	1.8	2.5	μs
Thermal Resistance, Junction-to-Case:	θ_{J-C}	-	-	8.5	-	-	8.5	$^oC/W$

♠ For either polarity of main terminal 2 voltage (V_{MT2}) with reference to main terminal 1.

† For either polarity of gate voltage (V_G) with reference to main terminal 1.

The following data are applicable to all triacs except as noted.

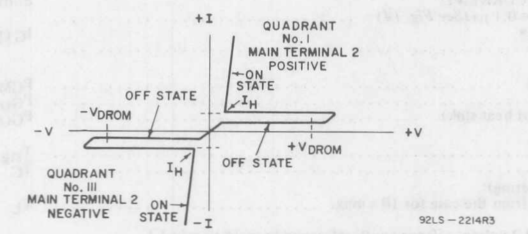


Fig. 1 — Principal voltage-current characteristic.

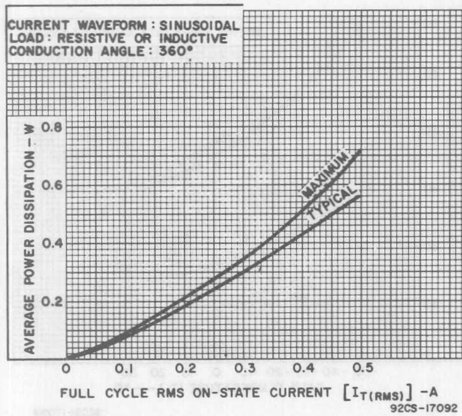


Fig. 2 — Power dissipation vs. on-state current.

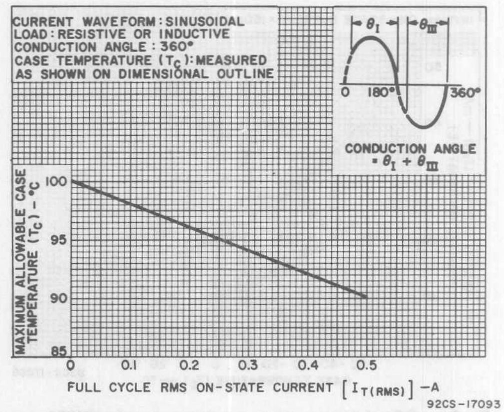


Fig. 3 — Maximum allowable case temperature vs. on-state current.

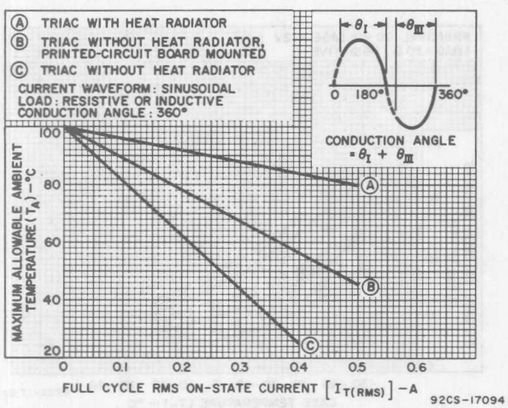


Fig. 4 — Maximum allowable ambient temperature vs. on-state current for the package/mounting options of these triacs.

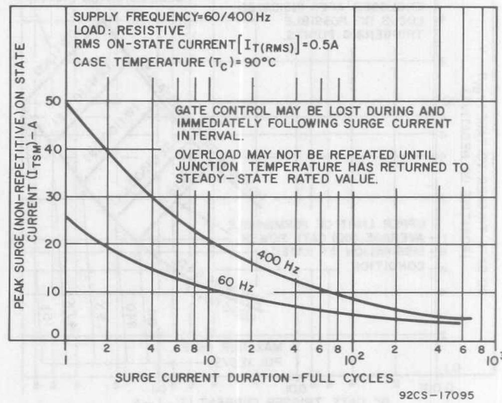


Fig. 5 — Peak surge on-stage current vs. surge-current duration.

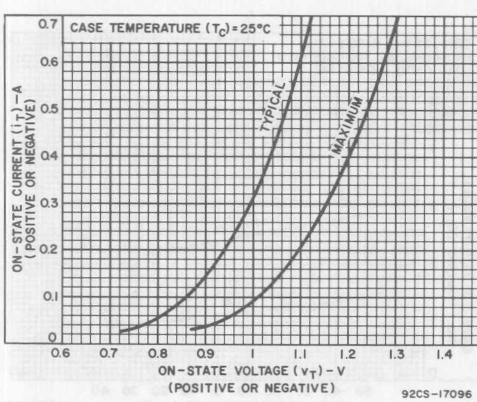


Fig. 6 — On-state current vs. on-state voltage (steady-state condition).

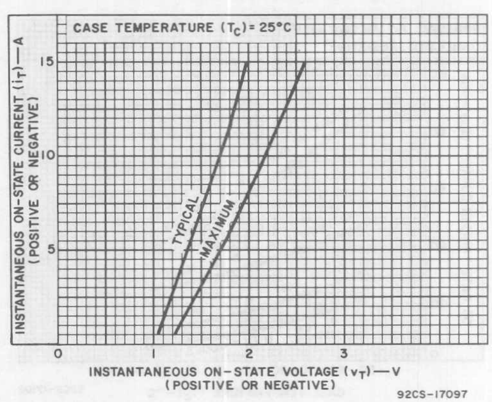


Fig. 7 — On-state current vs. on-state voltage (surge condition).

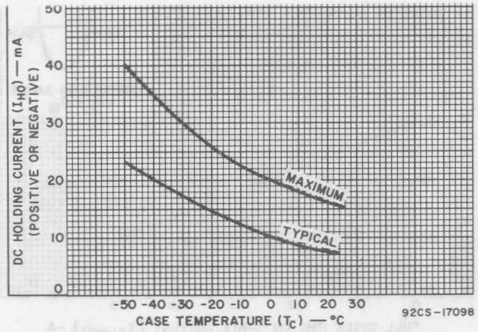


Fig. 8 — DC holding current vs. case temperature for T2304 series.

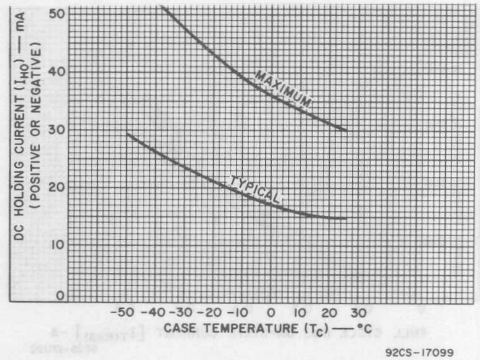


Fig. 9 — DC holding current vs. case temperature for T2305 series.

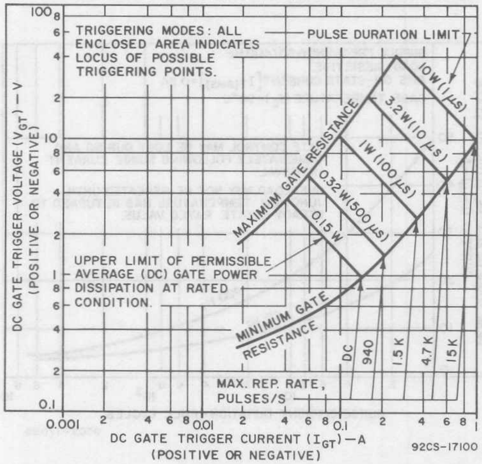


Fig. 10 — Gate trigger characteristics and limiting conditions for determination of permissible gate trigger pulses.

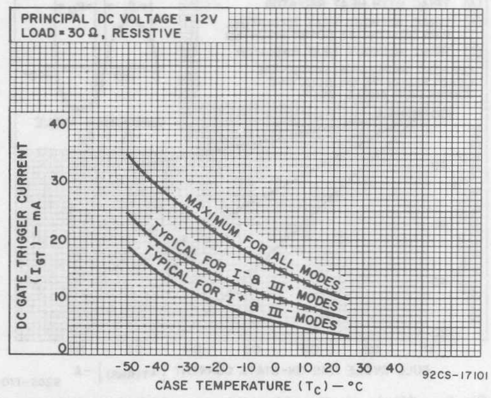


Fig. 11 — DC gate-trigger current vs. case temperature for T2304 series.

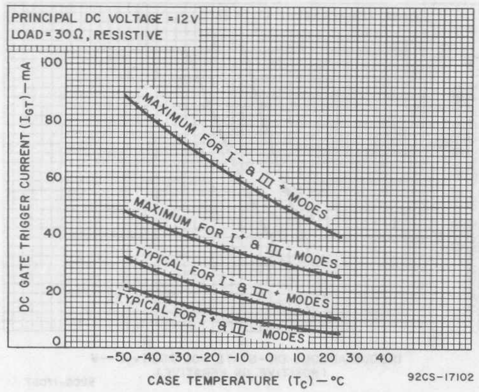


Fig. 12 — DC gate-trigger current vs. case temperature for T2305 series.

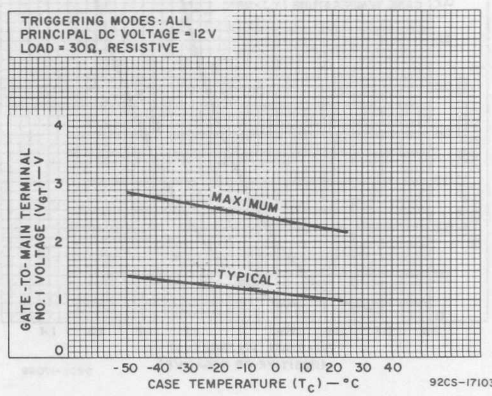


Fig. 13 — DC gate-trigger voltage vs. case temperature.

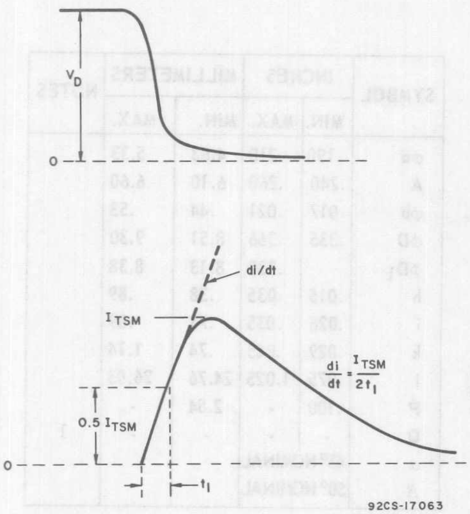


Fig. 14 – Rate-of-change of on-state current with time (defining di/dt).

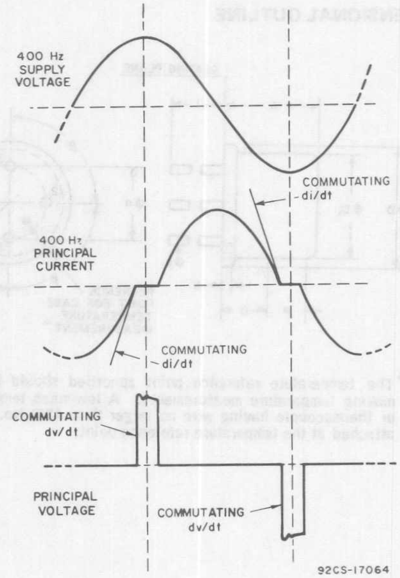


Fig. 15 – Relationship between supply voltage and principal current (inductive load) showing reference points for definition of commutating voltage (dv/dt).

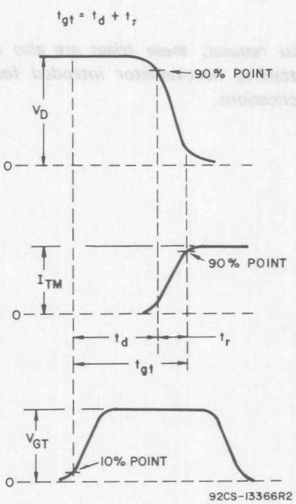
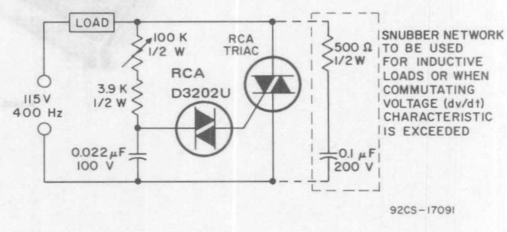


Fig. 16 – Relationship between off-state voltage, on-state current, and gate-trigger voltage showing reference points for definition of turn-on time (t_{gt}).

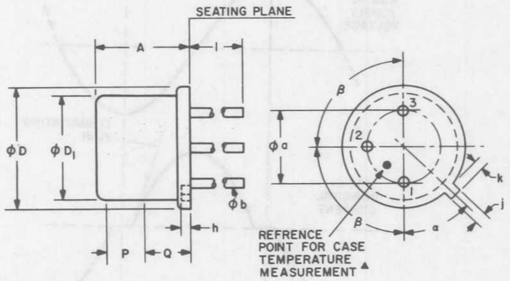


NOTE: For incandescent lamp loads which produce burnout current surges with I^2t values greater than 2.5 ampere^2 seconds, connect a 10 – ohm resistor of appropriate power rating in series with the load. This rating can be determined as follows:

$$\text{Power Rating of 10-ohm Resistor} = 10 \text{ (rms load current)}^2$$

Fig. 17 – Typical phase-control circuit for operation at 400 Hz.

DIMENSIONAL OUTLINE



▲The temperature reference point specified should be used when making temperature measurements. A low-mass temperature probe or thermocouple having wire no larger than AWG No. 16 should be attached at the temperature reference point.

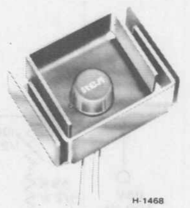
SYMBOL	INCHES		MILLIMETERS		NOTES
	MIN.	MAX.	MIN.	MAX.	
ϕa	.190	.210	4.83	5.33	
A	.240	.260	6.10	6.60	
ϕb	.017	.021	.44	.53	
ϕD	.335	.366	8.51	9.30	
ϕD_1		.330	8.13	8.38	
h	.015	.035	.38	.89	
i	.028	.035	.71	.89	
k	.029	.045	.74	1.14	
l	.975	1.025	24.76	26.03	
P	.100	-	2.54	-	
Q	-	-	-	-	1
α	45° NOMINAL				
β	50° NOMINAL				

Note 1: Details of outline in this zone optional.

92LM-2048R2

TERMINAL CONNECTIONS

Lead No. 1 - Main terminal 1
Lead No. 2 - Gate
Case, Lead No. 3 - Main terminal 2



On special request, these triacs are also available with a factory-attached heat-radiator intended for printed-circuit board applications.

RCA
Solid State
Division

Thyristors

T2306 T2806 T4107 T6406
T2316 T2616 T4116 T6407
T2606 T2716 T4117 T6416
T2706 T4106 T4706 T6417
Series

2.5–40-A, 100–600-V SILICON TRIACS DESIGNED FOR USE WITH IC ZERO-VOLTAGE SWITCHES AS TRIGGERING CIRCUITS

For Power-Control and Switching Applications at Frequencies of 50 to 60 Hz

These triacs are gate-controlled full-wave ac switches. They are intended for ac load-control applications such as heating controls (proportional or on-off); lamp switching, motor switching, and a wide variety of power-control applications.

The RCA CA3058, CA3059, and CA3079 are monolithic silicon IC zero-voltage switches designed for direct operation from the ac line. They can drive the triac gate directly and provide the gating signal at zero-voltage crossings for minimum radio-frequency interference.

These triacs have gate characteristics which assure that the zero-voltage switch can supply sufficient drive current to trigger them over the operating-temperature range from -40°C to +85°C. Ratings within this group of triacs range from 2.5 to 40 amperes rms on-state current, with repetitive off-state voltages available from 100 to 600 volts; and they employ a wide variety of packages.

RATINGS AND CHARACTERISTICS

Type No.	Former RCA Type No.	Rep. Peak Off-State Voltage V_{DROM} (V)	RMS On-State Current $I_{T(RMS)}$ (A)	at Case Temp. (°C)	Typ. DC Holding Current at 25°C, I_{HO} (mA)	Max. DC Gate Trigger Current and Voltage at 25°C▲ I+ I_{GT} (mA)	I+ V_{GT} (V)	III+ I_{GT} (mA)	III+ V_{GT} (V)	Package	For Additional Data, Refer to Bulletin File No.*
T2316A	40693	100	2.5	70	6	45	1.5	45	1.5	Mod. TO-5 on Heat Radiator	414
T2316B	40694	200	2.5	70	6	45	1.5	45	1.5	"	414
T2316D	40695	400	2.5	70	6	45	1.5	45	1.5	"	414
T2306A	40696	100	2.5	70	6	45	1.5	45	1.5	Mod. TO-5	414
T2306B	40697	200	2.5	70	6	45	1.5	45	1.5	"	414
T2306D	40698	400	2.5	70	6	45	1.5	45	1.5	Mod. TO-5	414
T6406B	40699	200	40	70	25	45	1.5	45	1.5	Press-fit	593
T6406D	40700	400	40	70	25	45	1.5	45	1.5	"	593
T6406M	40701	600	40	70	25	45	1.5	45	1.5	"	593
T6416B	40702	200	40	65	25	45	1.5	45	1.5	Stud	593
T6416D	40703	400	40	65	25	45	1.5	45	1.5	Stud	593
T6416M	40704	600	40	65	25	45	1.5	45	1.5	"	593
T6407B	40705	200	30	65	25	45	1.5	45	1.5	Press-fit	459
T6407D	40706	400	30	65	25	45	1.5	45	1.5	"	459
T6417B	40707	200	30	60	25	45	1.5	45	1.5	Stud	459
T6417D	40708	400	30	60	25	45	1.5	45	1.5	Stud	459
T6407M	40709	600	30	65	25	45	1.5	45	1.5	Press-fit	459
T6417M	40710	600	30	60	25	45	1.5	45	1.5	Stud	459
T4106B	40711	200	15	80	20	45	1.5	45	1.5	Press-fit	458
T4106D	40712	400	15	80	20	45	1.5	45	1.5	"	458

Type No.	Former RCA Type No.	Rep. Peak Off-State Voltage V_{DROM} (V)	RMS On-State Current $I_{T(RMS)}$ (A)	at Case Temp. (°C)	Typ. DC Holding Current at 25°C, I_{HO} (mA)	Max. DC Gate Trigger Current and Voltage at 25°C▲ I^+ I_{GT} (mA)	I^+ V_{GT} (V)	III^+ I_{GT} (mA)	III^+ V_{GT} (V)	Package	For Additional Data, Refer to Bulletin File No.*
T4116B	40713	200	15	80	20	45	1.5	45	1.5	Stud	458
T4116D	40714	400	15	80	20	45	1.5	45	1.5	"	458
T4706B	40715	200	15	70	15	45	1.5	45	1.5	TO-66	300
T4706D	40716	400	15	70	15	45	1.5	45	1.5	"	300
T4107B	40717	200	10	85	15	45	1.5	45	1.5	Press-fit	457
T4107D	40718	400	10	85	15	45	1.5	45	1.5	Press-fit	457
T4117B	40719	200	10	85	15	45	1.5	45	1.5	Stud	457
T4117D	40720	400	10	85	15	45	1.5	45	1.5	"	457
T2806B	40721	200	8	80	15	45	1.5	45	1.5	Plastic	364
T2806D	40722	400	8	80	15	45	1.5	45	1.5	"	364
T2706B	40727	200	6	75	15	45	1.5	45	1.5	TO-66	351
T2706D	40728	400	6	75	15	45	1.5	45	1.5	TO-66	351
T2716B	40729	200	6	75	15	45	1.5	45	1.5	TO-66 with Heat Radiator	351
T2716D	40730	400	6	75	15	45	1.5	45	1.5	"	351

▲ A triac driven directly from the output terminal of the CA3058, CA3059, and CA3079 should be characterized for operation in the I^+ or III^+ triggering modes, i.e., with positive gate current (current flows into the gate for both polarities of the applied ac voltage).

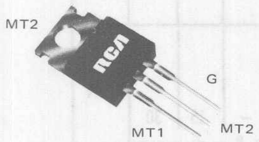
* Except for gate characteristics, data in these bulletins also apply to the types listed in this chart.

Technical information on RCA-CA3058, CA3059, and CA3079 is contained in bulletin File No. 490.

For detailed application information, see Application Note ICAN-6182, "Features and Application of RCA Integrated-Circuit Zero-Voltage Switches".

RCA Solid State Division

Thyristors
T2500B T2500D



JEDEC TO-220AB H-1535

6-A Silicon Triacs

Three-Lead Plastic Types for Power-Control and Power-Switching Applications

For 120-V Line Operation. . . . . . T2500B (41014)†
For 240-V Line Operation. . . . . . T2500D (41015)†

†Numbers in parentheses (e.g. 41014) are former RCA type numbers.

Features:

- 60-A Peak Surge Full-Cycle Current Ratings
- Shorted-Emitter, Center-Gate Design
- Low Switching Losses
- Low Thermal Resistance
- Package Design Facilitates Mounting on a Printed-Circuit Board

Types T2500B and T2500D* are gate-controlled full-wave silicon triacs utilizing a plastic case with three leads to facilitate mounting on printed-circuit boards. They are intended for the control of ac loads in such applications as motor controls, heating controls, relay replacement, solenoid drivers, static switching, and power-switching systems.

These devices are designed to switch from an off-state to an on-state for either polarity of applied voltage with positive or negative gate triggering voltages. They have an on-state current rating of 6 amperes at a T_C of 80°C and repetitive off-state voltage ratings of 200 volts and 400 volts, respectively.

The unique plastic package design provides not only ease of mounting but also low terminal impedance, which allows operation at high case temperatures and permits reduced heat-sink size.

*Formerly RCA Dev. Nos. TA8504 and TA8505.

MAXIMUM RATINGS, *Absolute-Maximum Values:*
For Operation with Sinusoidal Supply Voltage at Frequencies up to 50/60 Hz and with Resistive or Inductive Load.

		T2500B	T2500D	
REPETITIVE PEAK OFF-STATE VOLTAGE:●				
Gate open, T_J = −65 to 100°C	V_{DROM}	200	400	V
RMS ON-STATE CURRENT (Conduction angle = 360°):				
Case temperature	$I_{T(RMS)}$			
T_C = 80°C		6		A
For other conditions		See *Fig. 3*		
PEAK SURGE (NON-REPETITIVE) ON-STATE CURRENT:				
For one cycle of applied principal voltage	I_{TSM}			
60 Hz (sinusoidal)		60		A
50 Hz (sinusoidal)		50		A
For more than one cycle of applied principal voltage		See *Fig. 4*		
PEAK GATE-TRIGGER CURRENT:■				
For 10 μs max; see *Fig. 10*	I_{GTM}	4		A
GATE POWER DISSIPATION:				
Peak (For 1 μs max., $I_{GTM} \leq$ 4 A; see *Fig. 10)*	P_{GM}	16		W
AVERAGE	$P_{G(AV)}$	0.2		W
TEMPERATURE RANGE:▲				
Storage	T_{stg}	−65 to 150		°C
Operating (Case)	T_C	−65 to 100		°C
TERMINAL TEMPERATURE (During soldering):				
For 10 s max. (terminals and case)	T_T	225		°C

● For either polarity of main terminal 2 voltage (V_{MT2}) with reference to main terminal 1.
■ For either polarity of gate voltage (V_G) with reference to main terminal 1.
▲ For temperature measurement reference point, see *Dimensional Outline*.

ELECTRICAL CHARACTERISTICS at Maximum Ratings unless otherwise specified, and at indicated Case Temperature (T_C)

CHARACTERISTIC	SYMBOL	LIMITS T2500B MIN.	T2500B TYP.	T2500B MAX.	T2500D MIN.	T2500D TYP.	T2500D MAX.	UNITS
Peak Off-State Current:* Gate Open, V_{DROM} = Max. rated value At T_J = 100°C	I_{DROM}	–	0.1	2	–	0.1	2	mA
Maximum On-State Voltage:* For i_T = 30 A (peak) and T_C = 25°C	V_{TM}	–	1.7	2	–	1.7	2	V
DC Holding Current:* Gate Open, Initial principal current = 150 mA (dc) At T_C = 25°C	I_{HO}	–	15	30	–	15	30	mA
For other case temperatures		See Fig. 8.						
Critical Rate of Rise of Commutation Voltage:** For $v_D = V_{DROM}$, $I_{T(RMS)}$ = 6 A, Commutating di/dt = 3.2 A/ms, and gate unenergized At T_C = 80°C	dv/dt	4	10	–	4	10	–	V/μs
Critical Rate of Rise of Off-State Voltage:* For $v_D = V_{DROM}$, exponential voltage rise, and gate open At T_C = 100°C	dv/dt	100	300		75	250		V/μs
For other case temperatures		See Fig.9						
DC Gate-Trigger Current:*† For v_D = 12 V (dc), R_L = 12 Ω, T_C = 25°C, and specified triggering mode:								
I+ Mode (V_{MT2} positive, V_G positive)	I_{GT}	–	10	25	–	10	25	mA
III− Mode (V_{MT2} negative, V_G negative)	I_{GT}	–	15	25	–	15	25	mA
I− Mode (V_{MT2} positive, V_G negative)	I_{GT}	–	20	60	–	20	60	mA
III+ Mode (V_{MT2} negative, V_G positive)	I_{GT}	–	30	60	–	30	60	mA
For other case temperatures		See Figs. 12 and 13						
DC Gate-Trigger Voltage:*† For v_D = 12 V (dc) and R_L = 12 Ω At T_C = 25°C	V_{GT}	–	1.25	2.5	–	1.25	2.5	V
For other case temperatures		See Fig. 14.						
For $v_D = V_{DROM}$ and R_L = 125 Ω At T_C = 100°C	V_{GT}	0.2	–	–	0.2	–	–	V
Gate-Controlled Turn-On Time (Delay Time + Rise Time): For $v_D = V_{DROM}$, I_{GT} = 160 mA, rise time = 0.1 μs, and i_T = 10 A (peak) At T_C = 25°C (See Fig.15.)	t_{gt}	–	1.6	2.5	–	1.6	2.5	μs
Thermal Resistance: Junction-to-Case	$R_{\theta JC}$	–		2.7			2.7	°C/W
Junction-to-Ambient	$R_{\theta JA}$	–	–	60	–	–	60	°C/W

*For either polarity of main terminal 2 voltage (V_{MT2}) with reference to main terminal 1.

†For either polarity of gate voltage (V_G) with reference to main terminal 1.

♦Variants of these devices having dv/dt characteristics selected specifically for inductive loads are available on special order; for additional information, contact your RCA Representative or your RCA Distributor.

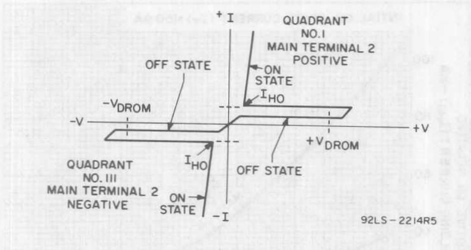


Fig. 1—Principal voltage-current characteristic.

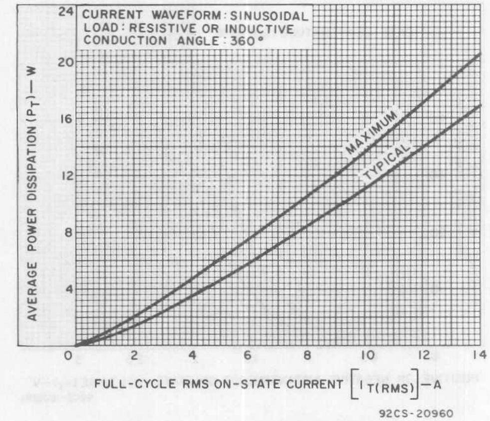


Fig. 2—Power dissipation vs. on-state current.

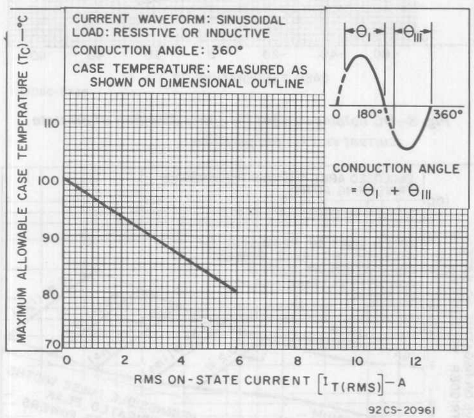


Fig. 3—Allowable case temperature vs. on-state current.

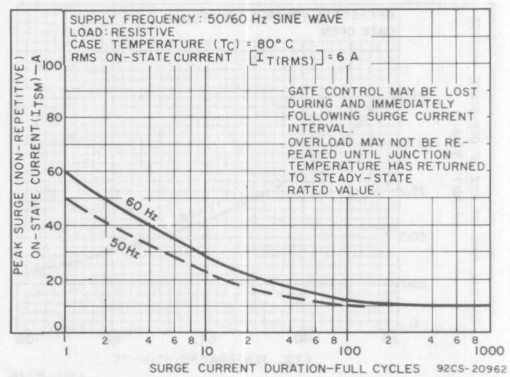


Fig. 4—Peak surge on-state current vs. surge current duration.

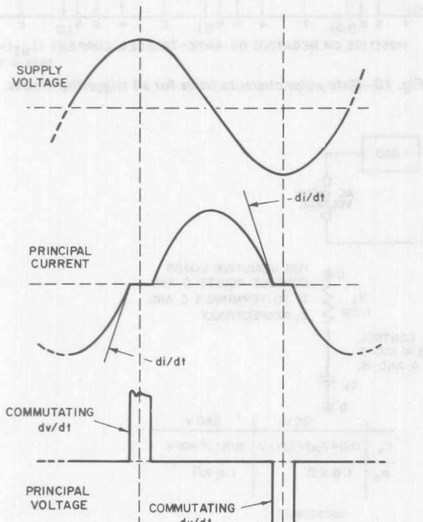


Fig. 5—Oscilloscope display of commutating dv/dt.

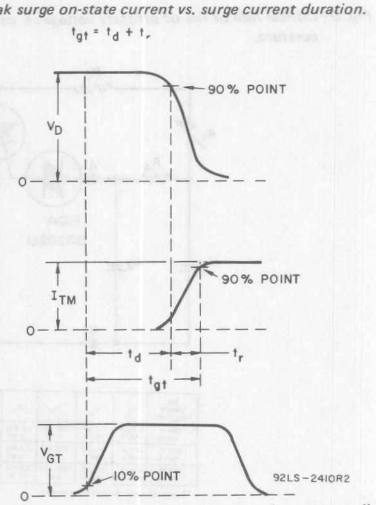


Fig. 6—Oscilloscope display for measurement of gate-controlled turn-on time (t_{gt}).

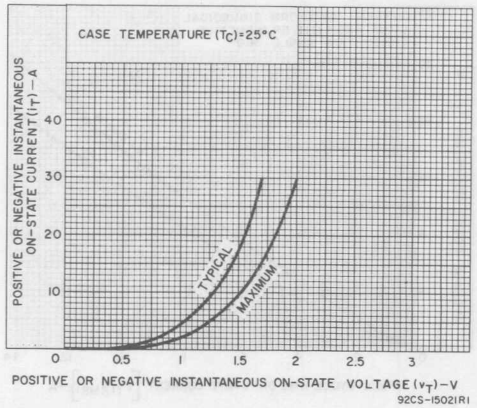


Fig. 7—On-state current vs. on-state voltage.

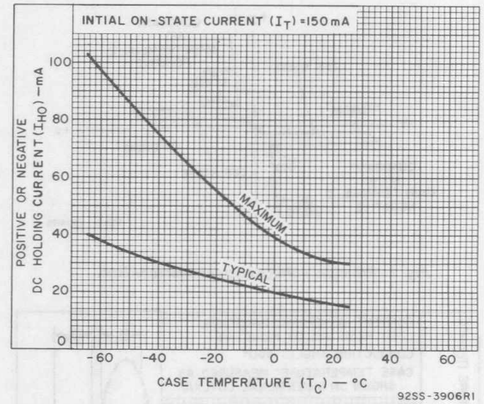


Fig. 8—DC holding current for either direction of on-state current vs. case temperature.

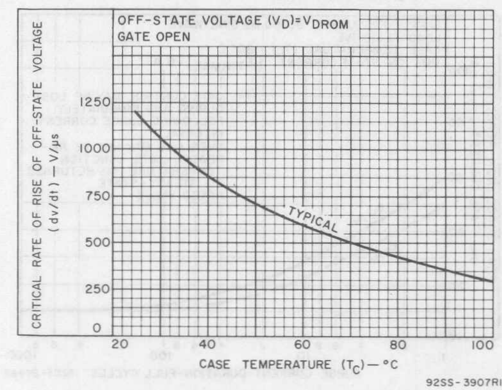


Fig. 9—Critical rate of rise of off-state voltage vs. case temperature.

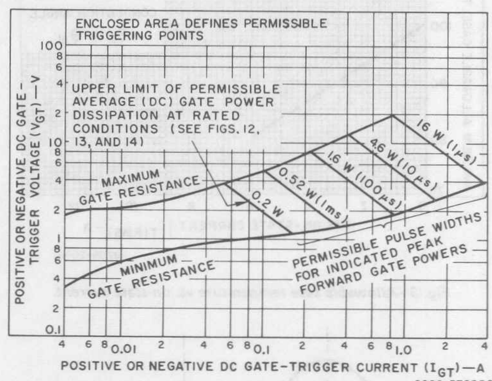
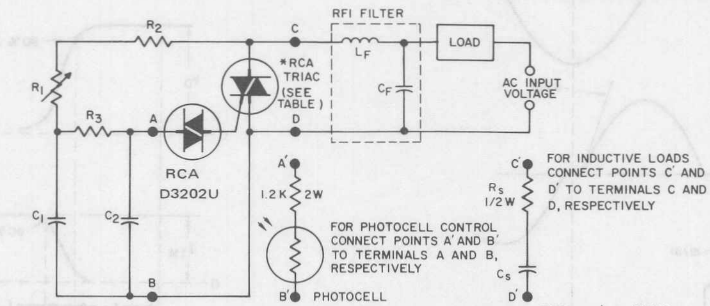


Fig. 10—Gate pulse characteristics for all triggering modes.



	120 V	240 V
C_S	0.047 µF/200 V	0.047 µF/400 V
R_S	1.8 KΩ	1.8 KΩ

92CS-20963R1

AC INPUT VOLTAGE	C_1	C_2	R_1	R_2	R_3	RFI FILTER L_F* (typ.)	RFI FILTER C_F* (typ.)	RCA TYPES
120 V 60 Hz	0.1 µF 200 V	0.1 µF 100 V	100 KΩ ½ W	2.2 KΩ ½ W	15 KΩ ½ W	100 µH	0.1 µF 200V	T2500B
240 V 50 Hz	0.1 µF 400 V	0.1 µF 100 V	250 KΩ 1 W	3.3 KΩ ½ W	15 KΩ ½ W	200 µH	0.1 µF 400 V	T2500D
240 V 60 Hz	0.1 µF 400 V	0.1 µF 100 V	200 KΩ 1 W	3.3 KΩ ½ W	15 KΩ ½ W	200 µH	0.1 µF 400 V	T2500D

*Typical values for lamp-dimming circuits.

Fig. 11 — Typical phase-control circuit for lamp dimming, heat controls, and universal motor speed controls.

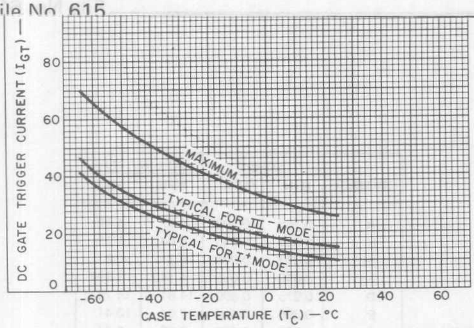


Fig. 12—DC gate-trigger current (for I^+ and III^- triggering modes) vs. case temperature.

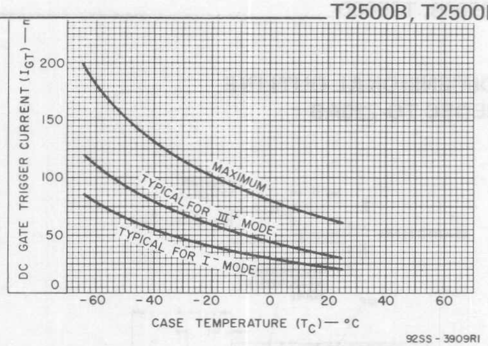


Fig. 13—DC gate-trigger current (for I^- and III^+ triggering modes) vs. temperature.

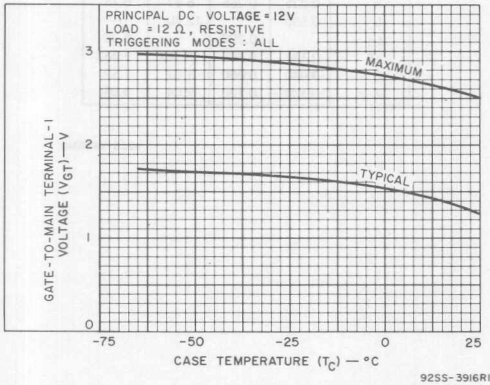


Fig. 14—DC gate-trigger voltage vs. case temperature.

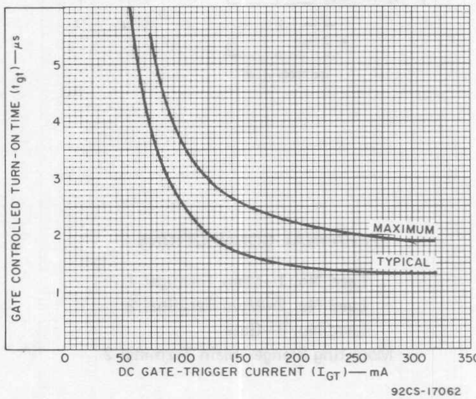
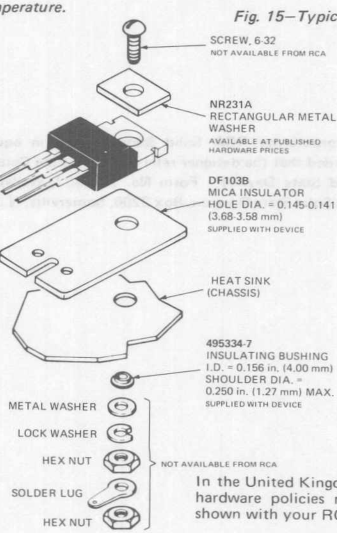


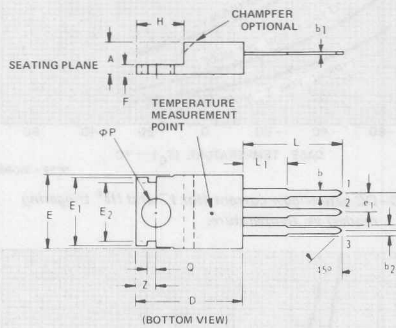
Fig. 15—Typical turn-on time vs. gate-trigger current.



In the United Kingdom, Europe, Middle East, and Africa, mounting-hardware policies may differ; check the availability of all items shown with your RCA sales representative or supplier.

Fig. 16—Suggested mounting hardware.

DIMENSIONAL OUTLINE
JEDEC TO-220AB



SYMBOL	INCHES MIN.	INCHES MAX.	MILLIMETERS MIN.	MILLIMETERS MAX.
A	0.160	0.190	4.07	4.82
b	0.025	0.040	0.64	1.02
b_1	0.012	0.020	0.31	0.51
b_2	0.045	0.055	1.143	1.397
D	0.575	0.600	14.61	15.24
E	0.395	0.410	10.04	10.41
E_1	0.365	0.385	9.28	9.77
E_2	0.300	0.320	7.62	8.12
e	0.180	0.220	4.57	5.58
e_1	0.080	0.120	2.03	3.04
F	0.020	0.055	0.51	1.39
H	0.235	0.265	5.97	6.73
L	0.500		12.70	
L_1	-	0.250	–	6.35
ϕP	0.141	0.145	3.582	3.683
Q	0.040	0.060	1.02	1.52
Z	0.100	0.120	2.54	3.04

92CS-19700R1

TERMINAL CONNECTIONS

Lead No. 1—Main Terminal 1
Lead No. 2—Main Terminal 2
Lead No. 3—Gate
Mounting Flange—Main Terminal 2

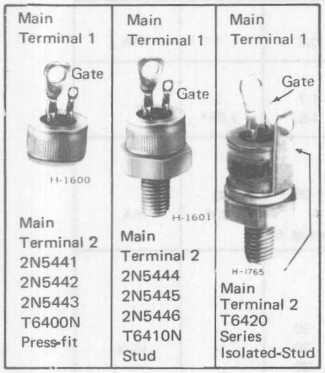
When incorporating RCA Solid State Devices in equipment, it is recommended that the designer refer to "Operating Considerations for RCA Solid State Devices", Form No. 1CE-402, available on request from RCA Solid State Division, Box 3200, Somerville, N.J. 08876.

File No. 593

RCA
Solid State
Division

Thyristors

2N5441 2N5442 2N5443 2N5444 2N5445 2N5446 T6400 T6410 T6420 Series



40-A Silicon Triacs

Press-Fit, Stud, and Isolated-Stud Packages

For 120-V Line Operation . . . 2N5441, 2N5444, T6420B (40688)†
For 240-V Line Operation . . . 2N5442, 2N5445, T6420D (40689)†
For High-Voltage Operation. . 2N5443, 2N5446, T6420M (40690)† T6400N, T6410N, T6420N (40925, 40926, 40927)†

†Numbers in parentheses (e.g. 40688) are former RCA type numbers.

Features:

- **di/dt Capability = 100 A/μs**
- **Shorted-Emitter, Center-Gate Design**
- **Low Switching Losses**
- **Low On-State Voltage at High Current Levels**
- **Low Thermal Resistance**

RCA triacs are gate-controlled, full-wave silicon ac switches. They are designed to switch from an off-state to an on-state for either polarity of applied voltage with positive or negative gate-triggering voltages.

MAXIMUM RATINGS, *Absolute-Maximum Values:*
For Operation with Sinusoidal Supply Voltage at Frequencies up to 50/60 Hz and with Resistive or Inductive Load.

		2N5441 2N5444 T6420B	2N5442 2N5445 T6420D	2N5443 2N5446 T6420M	T6400N T6410N T6420N	
***REPETITIVE PEAK OFF-STATE VOLTAGE:**•	V_{DROM}					
Gate open, T_J = −65 to 110°C		200	400	600	800	V
RMS ON-STATE CURRENT (Conduction angle = 360°):	$I_{T(RMS)}$					
Case temperature						
* T_C = 70°C (Press-fit types)		40				A
* = 65°C (Stud types)		40				A
= 60°C (Isolated-stud types)		40				A
For other conditions		See *Fig. 3*				
PEAK SURGE (NON-REPETITIVE) ON-STATE CURRENT:	I_{TSM}					
For one cycle of applied principal voltage						
* 60 Hz (sinusoidal)		300				A
50 Hz (sinusoidal)		265				A
For more than one cycle of applied principal voltage		See *Fig. 4*				
RATE OF CHANGE OF ON-STATE CURRENT:	di/dt					
$V_{DM} = V_{DROM}$, I_{GT} = 200 mA, t_r = 0.1 μs (See *Fig. 13*)		100				A/μs
FUSING CURRENT (for Triac Protection):	I^2t					
T_J = −65 to 110°C, t = 1.25 to 10 ms		350				A^2s
***PEAK GATE-TRIGGER CURRENT:**■	I_{GTM}					
For 1 μs max., See *Fig. 7*		12				A
***GATE POWER DISSIPATION:**						
PEAK (For 10 μs max., $I_{GTM} \leq$ 4 A, See *Fig. 7*)	P_{GM}	40				W
AVERAGE	$P_{G(AV)}$	0.75				W
***TEMPERATURE RANGE:**▲						
Storage	T_{stg}	−65 to 150				°C
Operating (Case)	T_C	−65 to 110				°C
***TERMINAL TEMPERATURE** (During soldering):	T_T					
For 10 s max. (terminals and case)		225				°C

* In accordance with JEDEC registration data format (JS-14, RDF2) filed for the JEDEC (2N-Series) types.
• For either polarity of main terminal 2 voltage (V_{MT2}) with reference to main terminal 1.
■ For either polarity of gate voltage (V_G) with reference to main terminal
▲ For temperature measurement reference point, see Dimensional Outline.

ELECTRICAL CHARACTERISTICS

At Maximum Ratings Unless Otherwise Specified and at Indicated Case Temperature (T_C)

CHARACTERISTIC	SYMBOL	LIMITS FOR ALL TYPES UNLESS OTHERWISE SPECIFIED MIN.	TYP.	MAX.	UNITS
Peak Off-State Current:♠					
Gate open, T_J = 110°C, V_{DROM} = Max. rated value	I_{DROM}	–	0.2	4*	mA
Maximum On-State Voltage:♠					
For i_T = 100 A (peak), T_C = 25°C	V_{TM}	–	1.7	2	V
For i_T = 56 A (peak), T_C = 25°C	V_{TM}	–	1.5	1.85*	V
DC Holding Current:♠					
Gate open, Initial principal current = 500 mA (dc), v_D = 12V:					
T_C = 25°C	I_{HO}	–	25	60	mA
T_C = -65°C	I_{HO}	–	–	100*	mA
For other case temperatures	I_{HO}	See *Fig. 6*			
Critical Rate of Rise of Commutation Voltage:♠					
For v_D = V_{DROM}, $I_{T(RMS)}$ = 40 A, commutating di/dt = 22 A/ms, gate unenergized, (See *Fig. 14*):					
T_C = 70°C (Press-fit types)	dv/dt	5*	30	–	V/μs
= 65°C (Stud types)	dv/dt	5*	30	–	V/μs
= 60°C (Isolated-stud types)	dv/dt	5	30	–	V/μs
Critical Rate of Rise of Off-State Voltage:♠					
For v_D = V_{DROM}, exponential voltage rise, gate open, T_C = 110°C:					
2N5441, 2N5444, T6420B........................	dv/dt	50*	200	–	V/μs
2N5442, 2N5445, T6420D........................	dv/dt	30*	150	–	V/μs
2N5443, 2N5446, T6420M........................	dv/dt	20*	100	–	V/μs
T6400N, T6410N, T6420N........................	dv/dt	10	75	–	V/μs
DC Gate-Trigger Current:♠♦ For v_D = 12 V (dc), R_L = 30 Ω, T_C = 25°C — Mode / V_{MT2} / V_G					
I+ positive positive	I_{GT}	–	15	50	mA
III− negative negative	I_{GT}	–	20	50	mA
I− positive negative	I_{GT}	–	30	80	mA
III+ negative positive	I_{GT}	–	40	80	mA
For v_D = 12 V (dc), R_L = 30 Ω, T_C = -65°C — Mode / V_{MT2} / V_G					
I+ positive positive	I_{GT}	–	–	125*	mA
III− negative negative	I_{GT}	–	–	125*	mA
I− positive negative	I_{GT}	–	–	240*	mA
III+ negative positive	I_{GT}	–	–	240*	mA
For other case temperatures	I_{GT}	See *Figs. 8 & 9*			
DC Gate-Trigger Voltage:♠♦					
For v_D = 12 V (dc), R_L = 30 Ω,					
T_C = 25°C	V_{GT}	–	1.35	2.5	V
= -65°C	V_{GT}	–	1.8	3.4*	V
For other case temperatures	V_{GT}	See *Fig. 10*			
For v_D = V_{DROM}, R_L = 125 Ω, T_C = 110°C	V_{GT}	0.2	–	–	V
Gate-Controlled Turn-On Time: (Delay Time + Rise Time) For v_D = V_{DROM}, I_{GT} = 200 mA, t_r = 0.1 μs, i_T = 60 A (peak), T_C = 25°C (See *Figs. 11 & 15*)	t_{gt}	–	1.7	3	μs
Thermal Resistance, Junction-to-Case:					
Steady-State					
Press-fit types	$R_{\theta JC}$	–	–	0.8*	°C/W
Stud types	$R_{\theta JC}$	–	–	0.9*	°C/W
Isolated-stud types	$R_{\theta JC}$	–	–	1	°C/W
Transient (Press-fit & stud types)	$R_{\theta JC}$	See *Fig. 12*			

* In accordance with JEDEC registration data format (JS-14, RDF 2) filed for the JEDEC (2N-Series) types.

♠ For either polarity of main terminal 2 voltage (V_{MT2}) with reference to main terminal 1.

♦ For either polarity of gate voltage (V_G) with reference to main terminal 1.

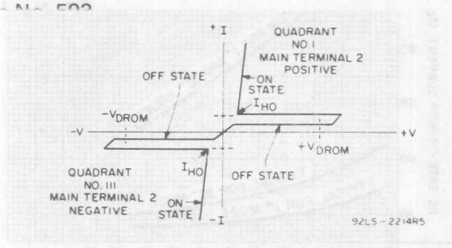


Fig.1—Principal voltage-current characteristic.

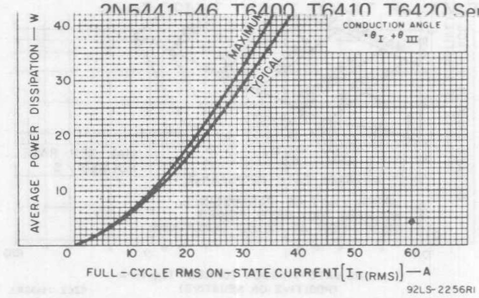


Fig.2—Power dissipation vs. on-state current.

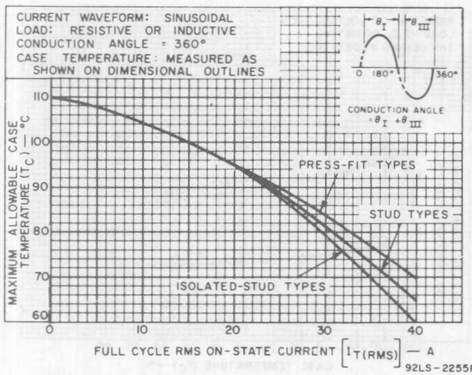


Fig.3—Maximum allowable case temperature vs. on-state current.

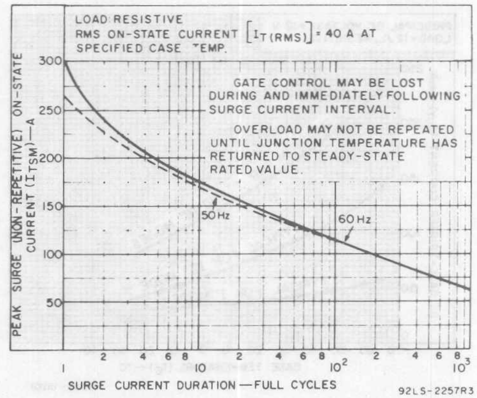


Fig.4—Peak surge on-state current vs. surge current duration.

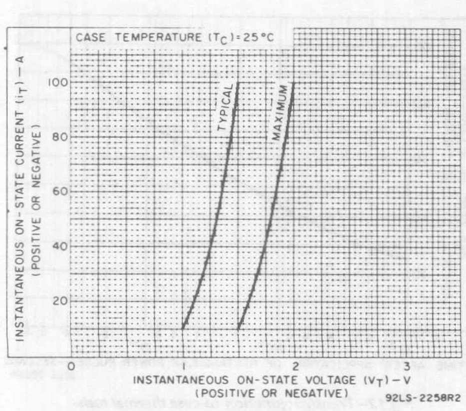


Fig.5—On-state current vs. on-state voltage.

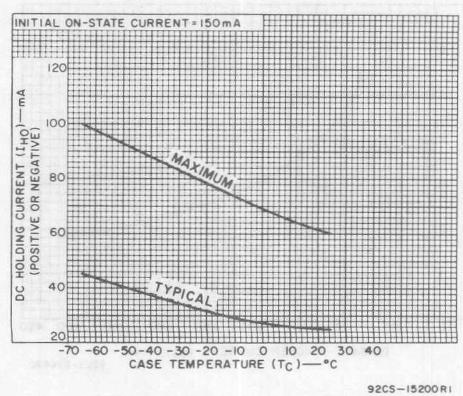


Fig.6—DC holding current vs. case temperature.

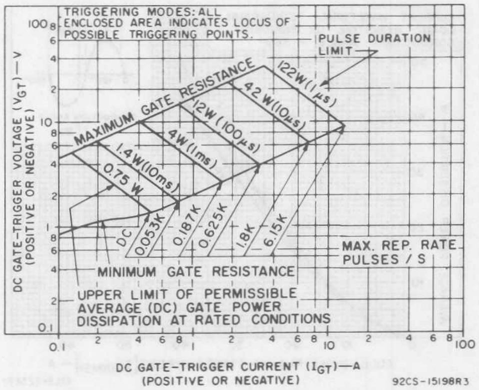


Fig.7—Gate-trigger characteristics and limiting conditions for determination of permissable gate-trigger pulses.

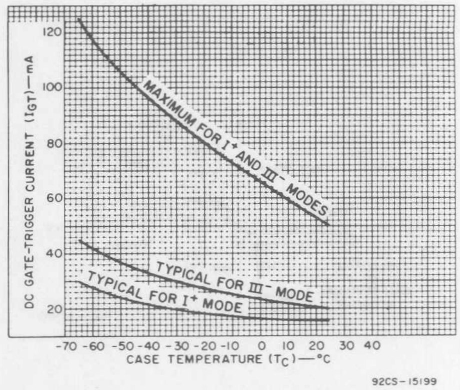


Fig.8—DC gate-trigger current vs. case temperature (I^+ & III^- modes).

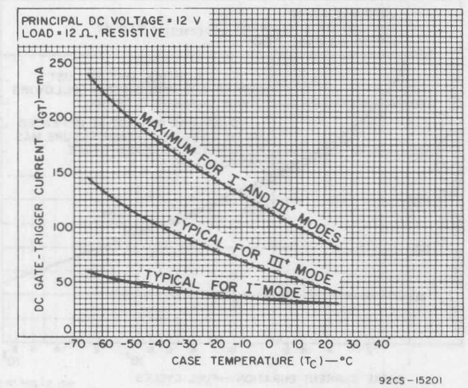


Fig.9—DC gate-trigger current vs. case temperature (I^- & III^+ modes).

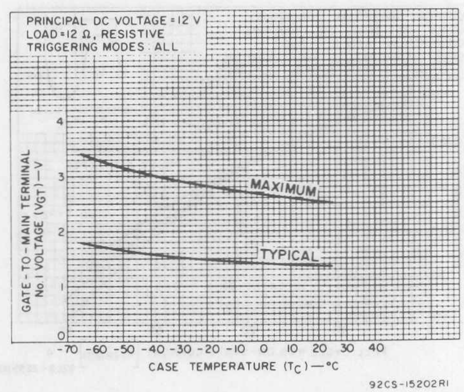


Fig.10—DC gate-trigger voltage vs. case temperature.

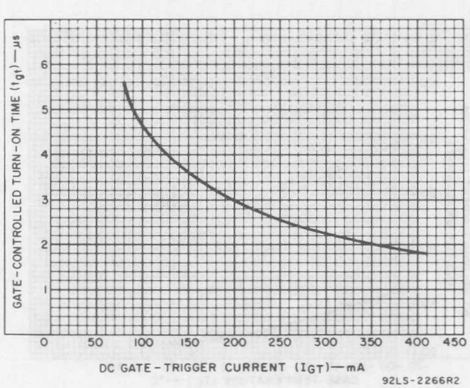


Fig.11—Turn-on time vs. gate-trigger current.

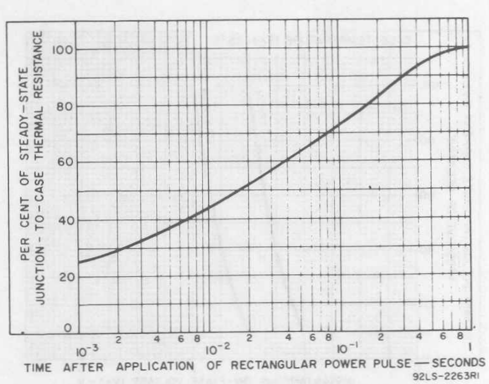


Fig.12—Transient junction-to-case thermal resistance vs. time for press-fit and stud types.

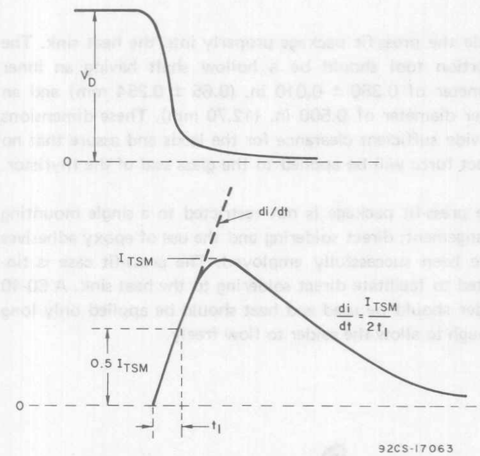


Fig.13—Rate of change of on-state current with time (defining di/dt).

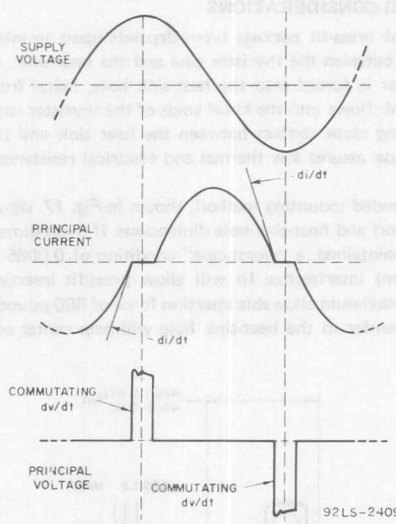


Fig.14—Relationship between supply voltage and principal current (inductive load) showing reference points for definition of commutating voltage (dv/dt).

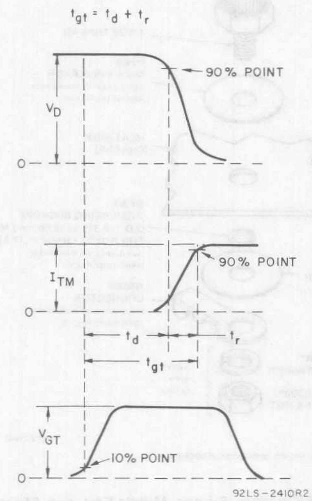
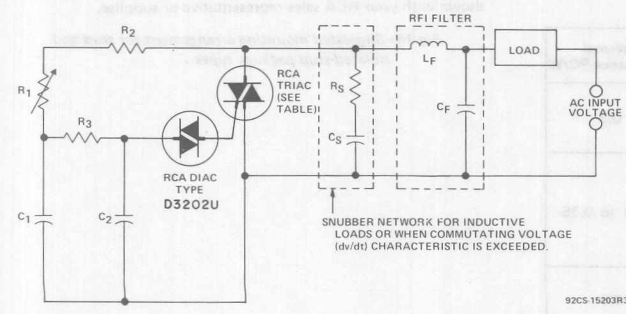


Fig.15—Relationship between off-state voltage, on-state current, and gate-trigger voltage showing reference points for definition of turn-on time (t_{gt}).



AC INPUT VOLTAGE		120V 60Hz	240V 60Hz	240V 50Hz
C_1		0.1μF 200V	0.1μF 400V	0.1μF 400V
C_2		0.1μF 100V	0.1μF 100V	0.1μF 100V
R_1		100KΩ 1/2W	200KΩ 1W	250KΩ 1W
R_2		2.2KΩ 1/2W	3.3KΩ 1/2W	3.3KΩ 1/2W
R_3		15KΩ 1/2W	15KΩ 1/2W	15KΩ 1/2W
SNUBBER NETWORK FOR 40-A (RMS)• INDUCTIVE LOAD	C_S	0.18-0.22μF 200V	0.18-0.22μF 400V	0.18-0.22μF 400V
	R_S	330-390Ω 1/2W	330-390Ω 1/2W	330-390Ω 1/2W
RFI FILTER	C_F*	0.1μF 200V	0.1μF 400V	0.1μF 400V
	L_F*	100μH	200μH	200μH
RCA TRIACS		2N5441 2N5444 T6420B	2N5442 2N5445 T6420D	2N5442 2N5445 T6420D

• For other RMS-current values refer to RCA Application Note AN-4745.

* Typical values for lamp dimming circuits.

Fig.16—Typical phase-control circuit for lamp dimming, heat control, and universal-motor speed control.

MOUNTING CONSIDERATIONS

Mounting of press-fit package types depends upon an interference fit between the thyristor case and the heat sink. As the thyristor is forced into the heat-sink hole, metal from the heat sink flows into the knurl voids of the thyristor case. The resulting close contact between the heat sink and the thyristor case assures low thermal and electrical resistances.

A recommended mounting method, shown in *Fig. 17,* shows press-fit knurl and heat-sink hole dimensions. If these dimensions are maintained, a "worst-case" condition of 0.0085 in (0.2159 mm) interference fit will allow press-fit insertion below the maximum allowable insertion force of 800 pounds. A slight chamfer in the heat-sink hole will help center and guide the press-fit package properly into the heat sink. The insertion tool should be a hollow shaft having an inner diameter of 0.380 ± 0.010 in. (9.65 ± 0.254 mm) and an outer diameter of 0.500 in. (12.70 mm). These dimensions provide sufficient clearance for the leads and assure that no direct force will be applied to the glass seal of the thyristor.

The press-fit package is not restricted to a single mounting arrangement; direct soldering and the use of epoxy adhesives have been successfully employed. The press-fit case is tin-plated to facilitate direct soldering to the heat sink. A 60-40 solder should be used and heat should be applied only long enough to allow the solder to flow freely.

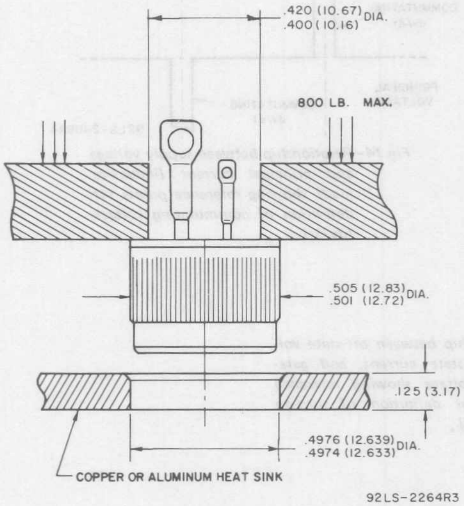
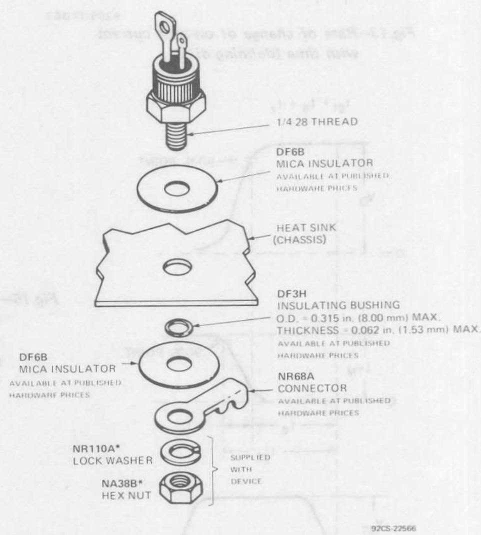


Fig. 17–Suggested mounting method for press-fit package types.



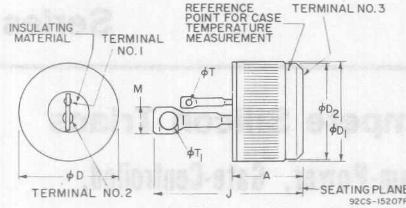
* Only hardware required for isolated-stud package.

In the United Kingdom, Europe, Middle East, and Africa, mounting-hardware policies may differ; check the availability of all items shown with your RCA sales representative or supplier.

Fig. 18–Suggested mounting arrangement for stud and isolated-stud package types .

Package	Type of Mounting Employed	Thermal Resistance-°C/W
Press-Fit	Press-fitted into heat sink. Minimum required thickness of heat sink = 1/8 in (3.17 mm)	0.5
	Soldered directly to heat sink. (60-40 solder which has a melting point of 188° C should be used. Heating time should be sufficient to cause solder to flow freely).	0.1 to 0.35
Stud	Directly mounted on heat sink with or without the use of heat-sink compound.	0.6

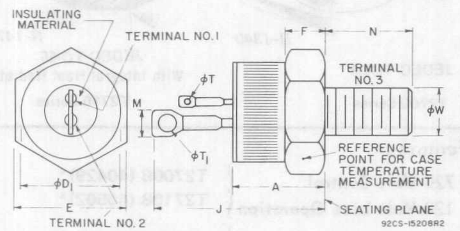
DIMENSIONAL OUTLINE FOR TYPES
2N5441, 2N5442, 2N5443, T6400N
PRESS-FIT



SYMBOL	INCHES		MILLIMETERS		NOTES
	MIN.	MAX.	MIN.	MAX.	
A	–	0.380	–	9.65	
ϕD	0.501	0.510	12.73	12.95	
ϕD_1	–	0.505	–	12.83	2
ϕD_2	0.465	0.475	11.81	12.07	
J	0.825	1.000	20.95	25.40	
M	0.215	0.225	5.46	5.71	1
ϕT	0.058	0.068	1.47	1.73	
ϕT_1	0.138	0.148	3.51	3.75	

NOTES:
1. Contour and angular orientation of these terminals is optional.
2. Outer diameter of knurled surface.

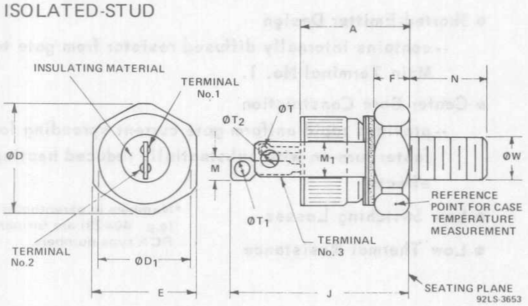
DIMENSIONAL OUTLINE FOR TYPES
2N5444, 2N5445, 2N5446, T6410N
STUD



SYMBOL	INCHES		MILLIMETERS		NOTES
	MIN.	MAX.	MIN.	MAX.	
A	0.330	0.505	8.4	12.8	
ϕD_1		0.544		13.81	
E	0.544	0.562	13.82	14.28	–
F	0.113	0.200	2.87	5.08	3
J	0.950	1.100	24.13	27.94	–
M	0.215	0.225	5.46	5.71	1
N	0.422	0.453	10.72	11.50	–
ϕT	0.058	0.068	1.47	1.73	–
ϕT_1	0.138	0.148	3.51	3.75	–
ϕW	¼-28	UNF-2A	¼-28	UNF-2A	2

NOTES:
1. Contour and angular orientation of these terminals is optional.
2. Pitch diameter of ¼-28 UNF-2A (coated) threads (ASA B1. 1-1960).
3. A chamfer or undercut on one or both ends of hexagonal portion is optional.

DIMENSIONAL OUTLINE FOR
T6420 SERIES
ISOLATED-STUD



SYMBOL	INCHES		MILLIMETERS		NOTES
	MIN.	MAX.	MIN.	MAX.	
A	–	0.673	–	17.09	
ϕD	0.604	0.614	15.34	15.59	
ϕD_1	0.501	0.505	12.72	12.82	
E	0.551	0.557	13.99	14.14	
F	0.100	0.110	2.54	2.79	
J	–	1.298		32.96	
M	0.210	0.230	5.33	5.84	
M_1	0.200	0.210	5.08	5.33	
N	0.422	0.452	10.72	11.48	
ϕT	0.058	0.068	1.47	1.73	2
ϕT_1	0.138	0.148	3.51	3.75	2
ϕT_2	0.138	0.148	3.51	3.75	2
ϕW	¼-28	UNF-2A	¼-28	UNF-2A	3

NOTES:
1. Ceramic between hex (stud) and terminal No. 3 is beryllium oxide.
2. Contour and angular orientation of these terminals is optional.
3. Pitch diameter of ¼-28 UNF-2A (coated) threads (ASA B1. 1-1960).

TERMINAL CONNECTIONS

No. 1—Gate
No. 2—Main Terminal 1
Case, No. 3—Main Terminal 2

RCA
Solid State
Division

Thyristors

T2700 T2710 Series

RCA T2700- and T2710-series devices are gate-controlled full-wave silicon triacs. They are intended for the control of ac loads in applications such as heating controls, motor controls, light dimmers, and power switching systems.

These triacs are designed to switch from an off-state to an on-state condition for either polarity of applied voltage with positive or negative triggering voltages to the gate.

T2700B and T2700D are hermetically sealed types having an on-state current rating of 6 amperes at a case temperature of +75°C and repetitive off-state voltage ratings of 200 volts and 400 volts, respectively.

These devices are also available with integral heat radiators, as T2710B and T2710D, respectively.

Maximum Ratings, *Absolute-Maximum Values:*

For Operation with Sinusoidal Supply Voltage at Frequencies of 50/60 Hz, and with Resistive or Inductive Load

	T2700B T2710B	T2700D T2710D	
REPETITIVE PEAK OFF-STATE VOLTAGE♦, V_{DROM}:			
Gate Open, For T_J = −65 to +100 °C	200	400	V
RMS ON-STATE CURRENT, $I_{t(rms)}$:			
For case temperature (T_C) of +75 °C and a conduction angle of 360°	6 (40429)	6 (40430)	A
For ambient temperatures (T_A) up to +100 °C and a conduction angle of 360°	See Fig. 16.		
PEAK SURGE (NON-REPETITIVE) ON-STATE CURRENT, I_{TSM}:			
For one cycle of applied principal voltage	100	100	A
For more than one full cycle of applied voltage	See Fig. 4.		
PEAK GATE-TRIGGER CURRENT■, I_{GTM}:			
For 1 μs max.	4	4	A
GATE POWER DISSIPATION:■			
PEAK, P_{GM} For 1 μs max. and $I_{GTM} \leq$ 4 A (peak)	16	16	W
AVERAGE, $P_{G(AV)}$	0.2	0.2	W
TEMPERATURE RANGE♦:			
Storage	−65 to +150		°C
Operating (case)	−65 to +100		°C

♦For either polarity of main terminal 2 voltage (V_{MT2}) with reference to main terminal 1.

■For either polarity of gate voltage (V_{GT}) with reference to main terminal 1.

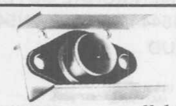
6-Ampere Silicon Triacs

Medium-Power, Gate-Controlled, Full-Wave Types

H-1340

JEDEC TO-66

T2700 Series



H-1470A

JEDEC TO-66
With Integral Heat Radiator

T2710 Series

Features

- 720-Watt Control 120-Volt Line Operation } T2700B (40429)* T2710B (40502)*
- 1,440-Watt Control 240-Volt Line Operation } T2700D (40430)* T2710D (40503)*
- 6-A (rms) On-State Current Ratings
- 100-A Peak Surge Full-Cycle Current Ratings
- Shorted-Emitter Design
  -- contains internally diffused resistor from gate to Main Terminal No. 1.
- Center Gate Construction
  -- provides rapid uniform gate current spreading for faster turn-on with substantially reduced heating effects
- Low Switching Losses
- Low Thermal Resistance

*Numbers in parentheses (e.g. 40429) are former RCA type numbers.

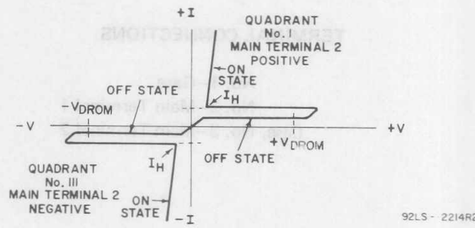


Fig. 1 — Principal voltage-current characteristic.

♦For information on the reference point of temperature measurement, see *Dimensional Outline.*

ELECTRICAL CHARACTERISTICS

At Maximum Ratings and at Indicated Case Temperature (T_C) Unless Otherwise Specified
(For Definitions of Terms and Symbols, See Page 6)

CHARACTERISTIC	SYMBOL	LIMITS												UNITS
		T2700B			T2710B			T2700D			T2710D			
		Min.	Typ.	Max.	Min.	Typ.	Max.	Min.	Typ.	Max.	Min.	Typ.	Max.	
Peak Off-State Current:* Gate Open At T_J = + 100 °C and V_{DROM} = Max. rated value	I_{DROM}	–	0.1	4	–	0.1	1.2	–	0.2	4	–	0.2	1.2	mA
Maximum On-State Voltage:* For i_T = 30A (peak) and T_C = +25 °C	v_{TM}	–	1.8	2.25	–	1.8	2.25	–	1.8	2.25	–	1.8	2.25	V
DC Holding Current:* Gate Open Initial principal current = 150 mA (DC) At T_C = +25 °C	I_{HO}	–	15	30	–	15	30	–	15	30	–	15	30	mA
For other case temperatures	I_{HO}	See Fig. 8.												mA
Critical Rate of Rise of Commutation Voltage:*♦ For V_D = V_{DROM}, $I_{t(rms)}$ = 6 A, commutating di/dt = 3.2 A/ms, and gate unenergized At T_C = +75 °C	dv/dt	3	10	–	–	–	–	3	10	–	–	–	–	V/μs
$I_{t(rms)}$ and T_A specified by curve A of Fig. 16.	dv/dt	–	–	–	3	10	–	–	–	–	3	10	–	V/μs
$I_{t(rms)}$ and T_A specified by curve B of Fig. 16	dv/dt	–	–	–	4	12	–	–	–	–	4	12	–	V/μs
Critical Rate of Rise of Off-State Voltage:* For V_D = V_{DROM}, exponential voltage rise, and gate open At T_C = + 100 °C	dv/dt	30	150	–	30	150	–	20	100	–	20	100	–	V/μs
DC Gate-Trigger Current:*† For V_D = 12 volts (DC), R_L = 12 Ω T_C = +25 °C, and specified triggering mode: I+ Mode: positive V_{MT2}, positive V_{GT}	I_{GT}	–	15	25	–	15	25	–	15	25	–	15	25	mA
III– Mode: negative V_{MT2}, negative V_{GT}	I_{GT}	–	15	25	–	15	25	–	15	25	–	15	25	mA
I– Mode: positive V_{MT2}, negative V_{GT}	I_{GT}	–	25	40	–	25	40	–	25	40	–	25	40	mA
III+ Mode: negative V_{MT2}, positive V_{GT}	I_{GT}	–	25	40	–	25	40	–	25	40	–	25	40	mA
For other case temperatures	I_{GT}	See Fig. 12 & 13.												mA
DC Gate-Trigger Voltage:*† For V_D = 12 volts (DC) and R_L = 12 Ω At T_C = +25 °C	V_{GT}	–	1	2.2	–	1	2.2	–	1	2.2	–	1	2.2	V
For other case temperatures	V_{GT}	See Fig. 14.												V
For V_D = V_{DROM} and R_L = 125 Ω At T_C = + 100 °C	V_{GT}	0.2	–	–	0.2	–	–	0.2	–	–	0.2	–	–	V
Gate-Controlled Turn-On Time: (Delay Time + Rise Time) For V_D = V_{DROM} and I_{GT} = 80 mA, 0.1 μs rise time, and i_T = 10 A (peak) At T_C = +25 °C	t_{gt}	–	2.2	–	–	2.2	–	–	2.2	–	–	2.2	–	μs
Thermal Resistance: Junction-to-Case (Steady-State)	θ_{J-C}	–	–	4	–	–	–	–	–	4	–	–	–	°C/W
Junction-to-Case (Transient)	θ_{J-C}	See Fig. 15.												°C/W
Junction-to-Ambient	θ_{J-A}	–	–	–	See Fig. 16.			–	–	–	See Fig. 16.			°C/W

*For either polarity of main terminal 2 voltage (V_{MT2}) with reference to main terminal 1.
†For either polarity of gate voltage (V_{GT}) with reference to main terminal 1.
♦Variants of these devices having dv/dt characteristics selected specifically for inductive loads are available on special order; for additional information, contact your RCA Representative or your RCA Distributor.

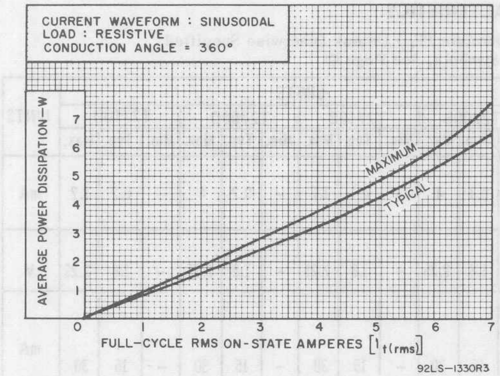


Fig. 2 — Power dissipation vs. on-state current.

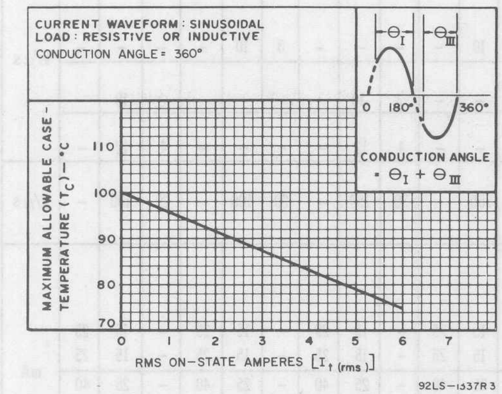


Fig. 3 — Allowable case temperature vs. on-state current.

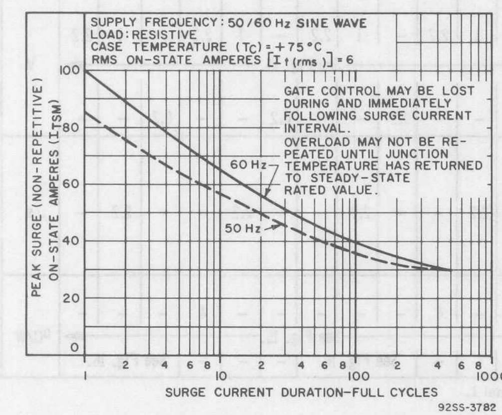


Fig. 4 — Peak surge on-state current vs. surge current duration.

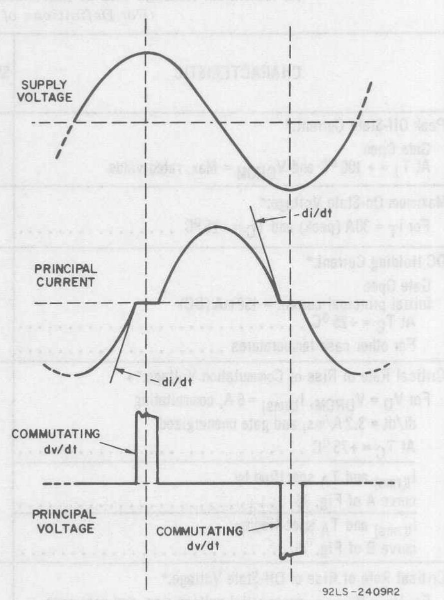


Fig. 5 — Oscilloscope display of commutating dv/dt.

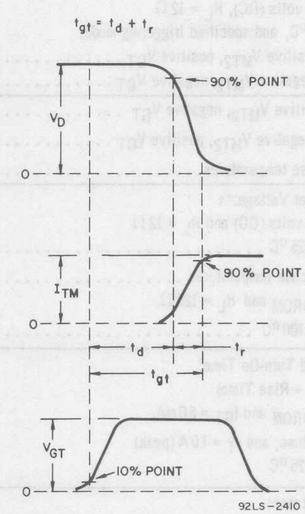


Fig. 6 — Oscilloscope display for measurement of gate-controlled turn-on time (t_{gt}).

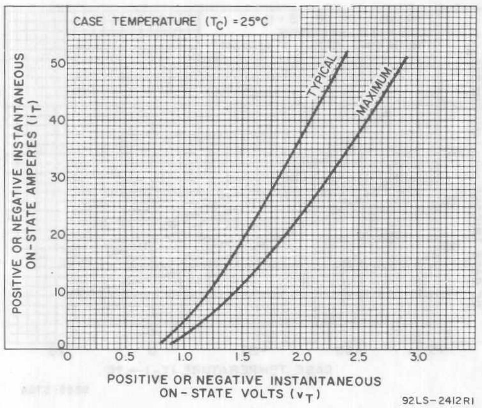


Fig. 7 — On-state current vs. on-state voltage.

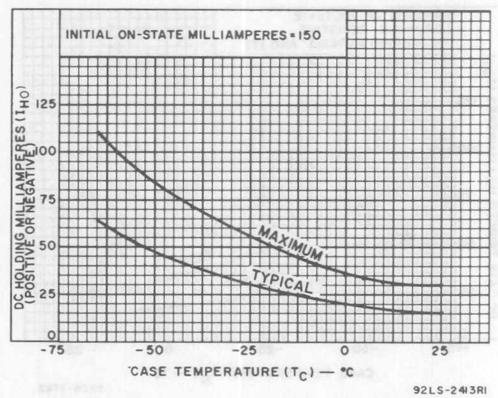


Fig. 8 — DC holding current for either direction of on-state current vs. case temperature.

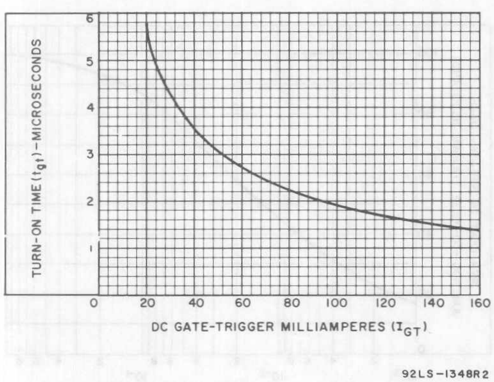


Fig. 9 — Typical turn-on time vs. gate-trigger current.

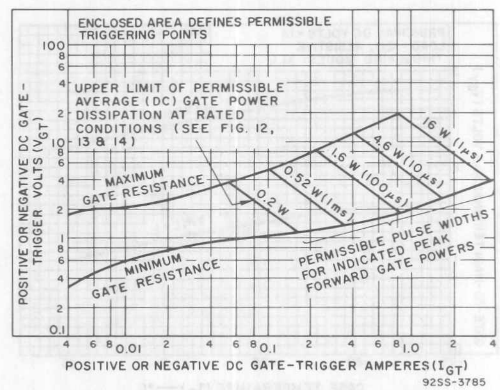
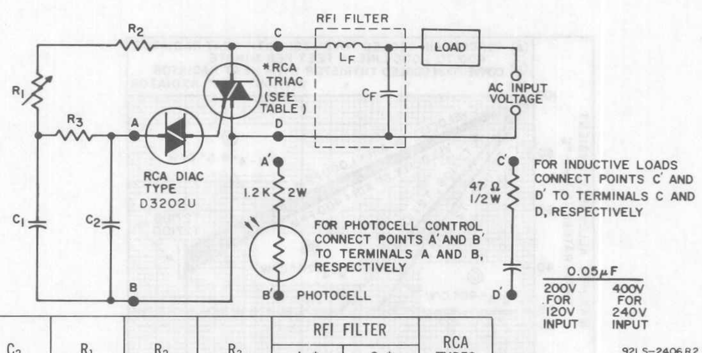


Fig. 10 — Gate pulse characteristics for all triggering modes.



AC INPUT VOLTAGE	C_1	C_2	R_1	R_2	R_3	RFI FILTER L_F* (typ.)	RFI FILTER C_F* (typ.)	RCA TYPES
120V 60Hz	0.1μF 200V	0.1μF 100V	100KΩ 1/2W	1KΩ 1/2W	15KΩ 1/2W	100μH	0.1μF 200V	**T2700B T2710B**
240V 50/60Hz	0.05μF 400V	0.1μF 100V	200KΩ 1/2W	7.5KΩ 2W	7.5KΩ 2W	100μH	0.1μF 400V	**T2700D T2710D**

*Typical values for lamp dimming circuits.

Fig. 11 — Typical phase-control circuit for lamp dimming, heat controls, and universal motor speed controls.

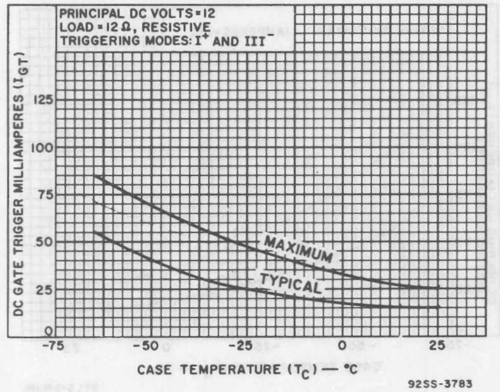


Fig. 12 — DC gate-trigger current (for I^+ and III^- triggering modes) vs. case temperature.

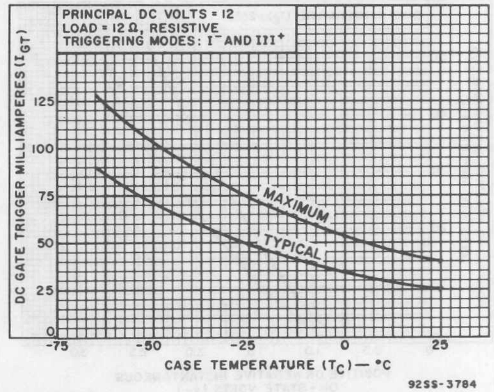


Fig. 13 — DC gate-trigger current (for I^- and III^+ triggering modes) vs. case temperature.

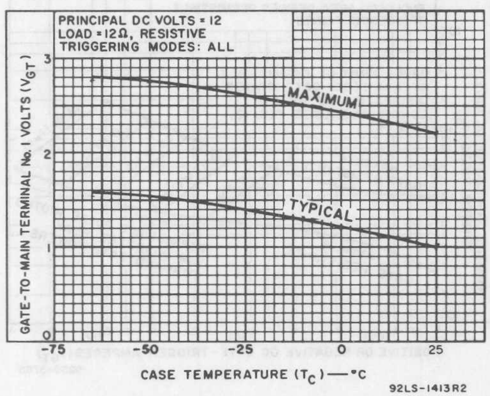


Fig. 14 — DC gate-trigger voltage vs. case temperature.

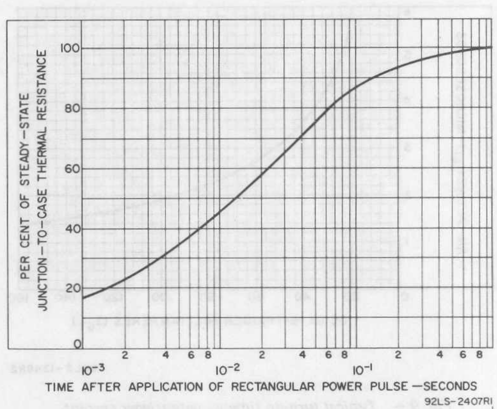


Fig. 15 — Transient thermal resistance (junction-to-case vs. time).

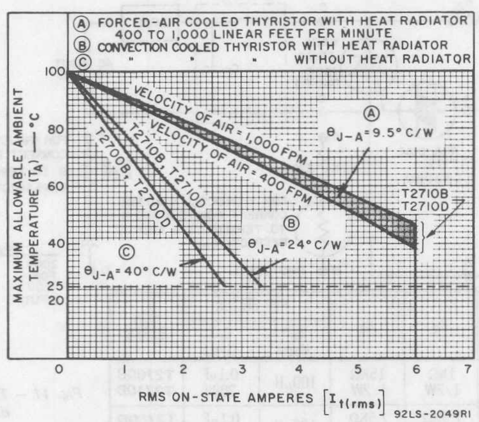
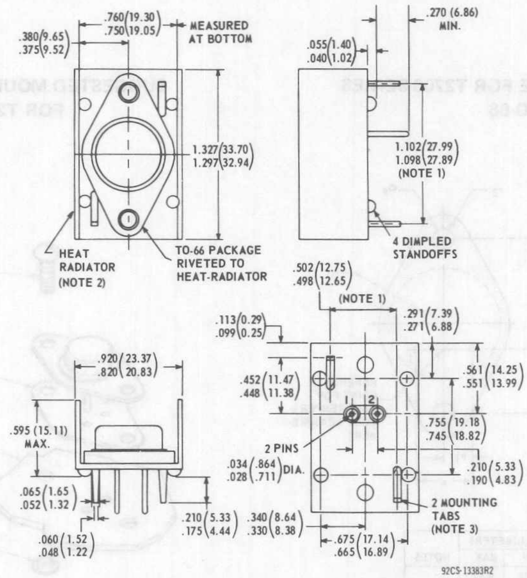


Fig. 16 — Maximum allowable ambient temperature vs. on-state current.

DIMENSIONAL OUTLINE FOR T2710 SERIES JEDEC TO-66 WITH HEAT-RADIATOR



Dimensions in Inches and Millimeters

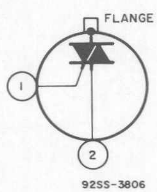
NOTE: *Dimensions in parentheses are in millimeters and are derived from the basic inch dimensions as indicated.*

Note 1: Measured at bottom of heat-radiator.

Note 2: 0.035 in. (.889) C.R.S., tin plated.

Note 3: Recommended hole size for printed-circuit board is 0.070 in. (1. 778) dia.

TERMINAL DIAGRAM FOR T2700 AND T2710 SERIES



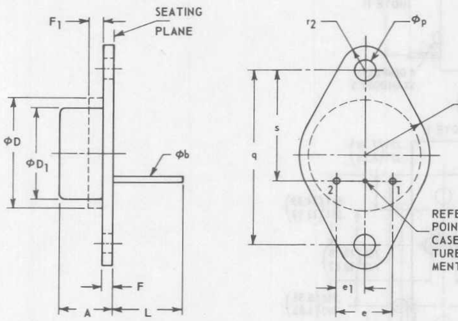
Pin 1 - Gate

Pin 2 - Main Terminal 1

Flange, Case - Main Terminal 2

Case, Flange (T2700 Series) - Main Terminal 2
Case, Flange, Heat Radiator (T2710 Series)

DIMENSIONAL OUTLINE FOR T2700 SERIES JEDEC TO-66



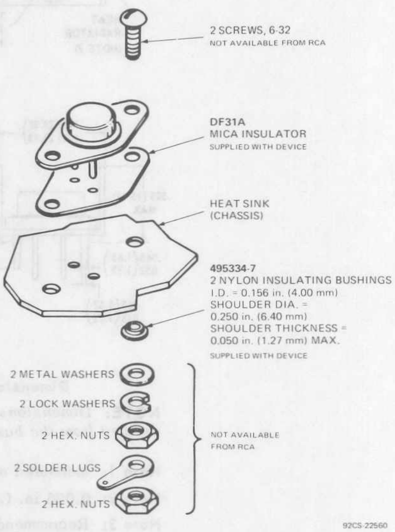
SYMBOL	INCHES		MILLIMETERS		NOTES
	MIN.	MAX.	MIN.	MAX.	
A	.250	.340	6.35	8.64	
ϕb	.028	.034	.711	.863	
ϕD		.620		15.75	
ϕD_1	.470	.500	11.94	12.70	
e	.190	.210	4.83	5.33	
e_1	.093	.107	2.36	2.72	
F	.050	.075	1.27	1.91	2
F_1		.050		1.27	1
L	.360		9.14		
ϕp	.142	.152	3.61	3.86	
q	.958	.962	24.33	24.43	
r_1		.350		8.89	
r_2		.145		3.68	
s	.570	.590	14.48	14.99	

NOTES:

1. THE OUTLINE CONTOUR IS OPTIONAL WITHIN ZONE DEFINED BY ϕD AND F_1.
2. DIMENSION DOES NOT INCLUDE SEALING FLANGES.

92SS-3738

SUGGESTED MOUNTING ARRANGEMENT FOR T2700 SERIES

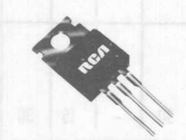


In the United Kingdom, Europe, Middle East, and Africa, mounting-hardware policies may differ; check the availability of all items shown with your RCA sales representative or supplier.

RCA
Solid State
Division

Thyristors

T2800B T2800D T2800M



JEDEC TO-220AB

H-1535

8-A Silicon Triacs

Three-Lead Plastic Types for
Power-Control and Power-Switching Applications

For 120-V Line Operation – T2800B (40668)*
For 240-V Line Operation – T2800D (40669)*
For High-Voltage Operation – T2800M (40670)*

*Numbers in parentheses (e.g. 40668) are former RCA type numbers.

Features:

- **100-A Peak Surge Full-Cycle Current Ratings**
- **Shorted-Emitter Center-Gate Design**
- **Low Switching Losses**
- **Low Thermal Resistance**
- **Package Design Facilitates Mounting on a Printed-Circuit Board**

RCA-T2800B, T2800D, and T2800M+ triacs are gate-controlled full-wave silicon switches utilizing a plastic case with three leads to facilitate mounting on printed-circuit boards. They are intended for the control of ac loads in such applications as motor controls, light dimmers, heating controls, and power-switching systems.

These devices are designed to switch from an off-state to an on-state for either polarity of applied voltage with positive or negative gate triggering voltages. They have an on-state current rating of 8 amperes at a T_C of 80°C and repetitive off-state voltage ratings of 200, 400, and 600 volts, respectively.

The unique plastic package design provides not only ease of mounting but also low thermal impedance, which allows operation at high case temperatures and permits reduced heat-sink size.

+Formerly RCA Dev. Nos. TA7364, TA7365, and TA7518, respectively.

MAXIMUM RATINGS, *Absolute-Maximum Values:*
For Operation with Sinusoidal Supply Voltage at Frequencies up to 50/60 Hz and with Resistive or Inductive Load.

		T2800B	T2800D	T2800M	
REPETITIVE PEAK OFF-STATE VOLTAGE:•					
Gate open, T_J = −65 to 100°C	V_{DROM}	200	400	600	V
RMS ON-STATE CURRENT (Conduction angle = 360°):					
Case temperature	$I_{T(RMS)}$				
T_C = 80°C			8		A
For other conditions			See *Fig. 3*		
PEAK SURGE (NON-REPETITIVE) ON-STATE CURRENT:					
For one cycle of applied principal voltage	I_{TSM}				
60 Hz (sinusoidal)			100		A
50 Hz (sinusoidal)			85		A
For more than one cycle of applied principal voltage			See *Fig. 4*		
PEAK GATE-TRIGGER CURRENT:■					
For 10 μs max., See *Fig. 11*	I_{GTM}		4		A
GATE POWER DISSIPATION:					
Peak (For 1 μs max., $I_{GTM} \leq 4$ A, See *Fig. 11*	P_{GM}		16		W
AVERAGE	$P_{G(AV)}$		0.2		W
TEMPERATURE RANGE:▲					
Storage	T_{stg}		−65 to 150		°C
Operating (Case)	T_C		−65 to 100		°C
TERMINAL TEMPERATURE (During soldering):					
For 10 s max. (terminals and case)	T_T		225		°C

• For either polarity of main terminal 2 voltage (V_{MT2}) with reference to main terminal 1.
■ For either polarity of gate voltage (V_G) with reference to main terminal 1.
▲ For temperature measurement reference point, see *Dimensional Outline*.

Peak Off-State Current:* Gate Open At T_J = +100°C and V_{DROM} = Max. rated value	I_{DROM}	–	0.1	2	–	0.1	2	–	0.1	2	mA
Maximum On-State Voltage:* For i_T = 30 A (peak) and T_C = +25 °C	v_{TM}	–	1.7	2	–	1.7	2	–	1.7	2	V
DC Holding Current:* Gate Open Initial principal current = 150 mA (DC) At T_C = +25 °C	I_{HO}	–	15	30	–	15	30	–	15	30	mA
For other case temperatures		See Fig. 8.									
Critical Rate of Rise of Commutation Voltage:*♦ For v_D = V_{DROM}, $I_{T(RMS)}$ = 8 A, Commutating di/dt = 4.3 A/ms, and gate unenergized At T_C = +80 °C	dv/dt	4	10	–	4	10	–	4	10	–	V/μs
Critical Rate-of-Rise of Off-State Voltage:* For v_D = V_{DROM}, exponential voltage rise, and gate open At T_C = + 100°C	dv/dt	100	300	–	75	250	–	60	200	–	V/μs
For other case temperatures		See Fig. 10.									
DC Gate-Trigger Current:*† For v_D = 12 V (DC), R_L = 12 Ω T_C = +25 °C, and specified triggering mode: I+ Mode: V_{MT2} is positive, V_G is positive	I_{GT}		10	25		10	25		10	25	mA
III– Mode: V_{MT2} is negative, V_G is negative		–	15	25	–	15	25	–	15	25	
I– Mode: V_{MT2} is positive, V_G is negative		–	20	60	–	20	60	–	20	60	
III+ Mode: V_{MT2} is negative, V_G is positive		–	30	60	–	30	60	–	30	60	
For other case temperatures		See Fig. 12. & 13.									
DC Gate-Trigger Voltage:*† For v_D = 12 V (DC) and R_L = 12 Ω At T_C = +25 °C	V_{GT}	–	1.25	2.5	–	1.25	2.5	–	1.25	2.5	V
For other case temperatures		See Fig. 14.									
For v_D = V_{DROM} and R_L = 125 Ω At T_C = +100 °C		0.2	–	–	0.2	–	–	0.2	–	–	
Gate-Controlled Turn-On Time: (Delay Time + Rise Time) For v_D = V_{DROM} and I_{GT} = 80 mA 0.1 μs rise time, and i_T = 10 A (peak) At T_C = +25 °C *(See Fig. 15).*	t_{gt}	–	1.6	2.5	–	1.6	2.5	–	1.6	2.5	μs
Thermal Resistance: Junction-to-Case	θ_{J-C}	–	–	2.2	–	–	2.2	–	–	2.2	°C/W
Junction-to-Ambient	θ_{J-A}	–	–	60	–	–	60	–	–	60	°C/W

*For either polarity of main terminal 2 voltage (V_{MT2}) with reference to main terminal 1.

†For either polarity of gate voltage (V_G) with reference to main terminal 1.

♦Variants of these devices having dv/dt characteristics selected specifically for inductive loads are available on special order; for additional information, contact your RCA Representative or your RCA Distributor.

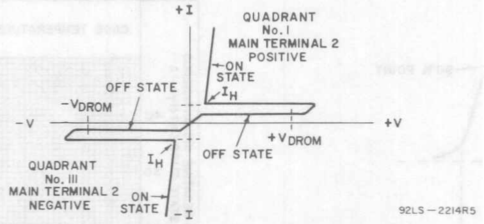


Fig. 1 — Principal voltage-current characteristic.

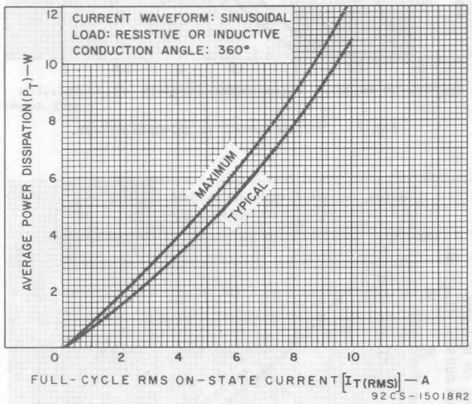


Fig. 2 — Power dissipation vs. on-state current.

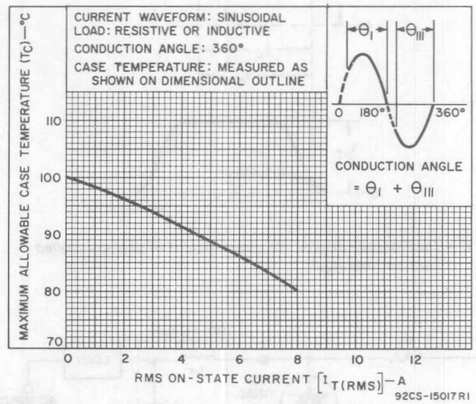


Fig. 3 — Allowable case temperature vs. on-state current.

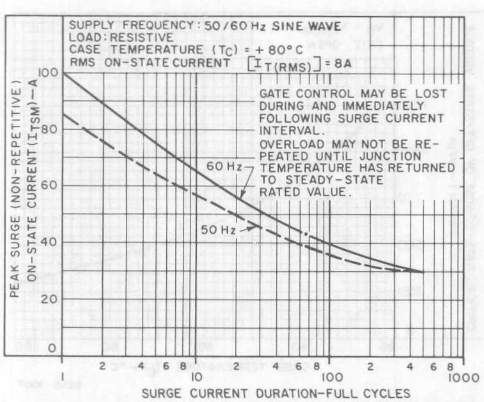


Fig. 4 — Peak surge on-state current vs. surge current duration.

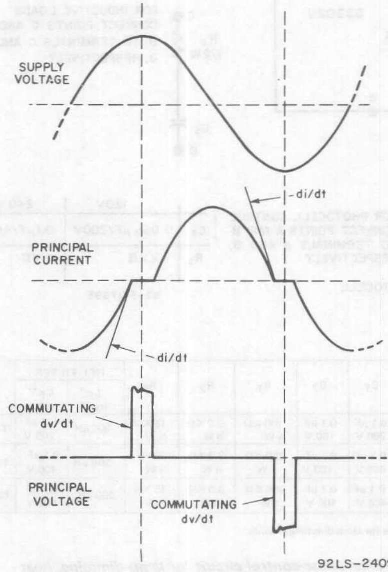


Fig. 5 — Oscilloscope display of commutating dv/dt.

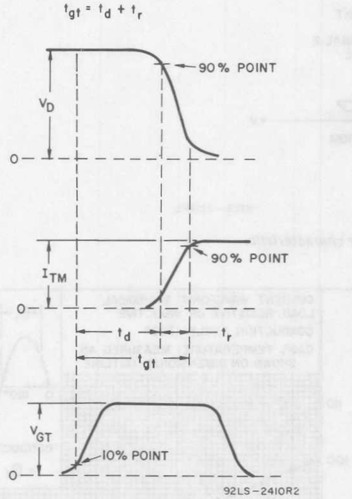


Fig. 6 — Oscilloscope display for measurement of gate-controlled turn-on time (t_{gt}).

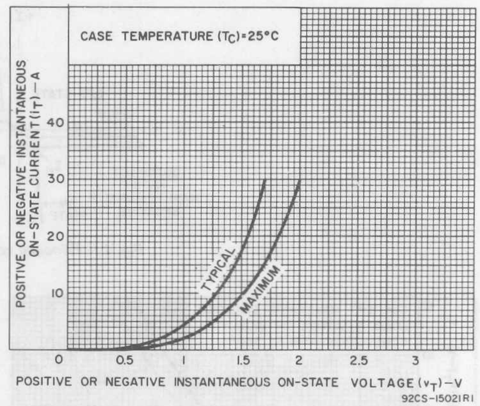


Fig. 7 — On-state current vs. on-state voltage.

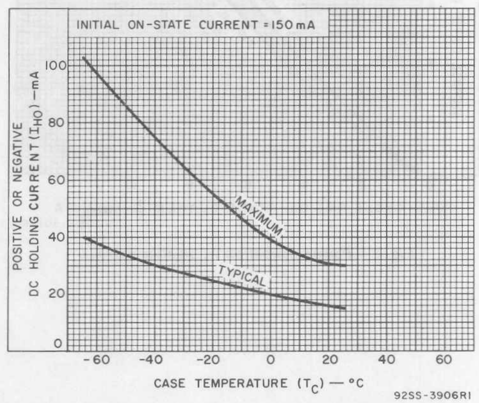
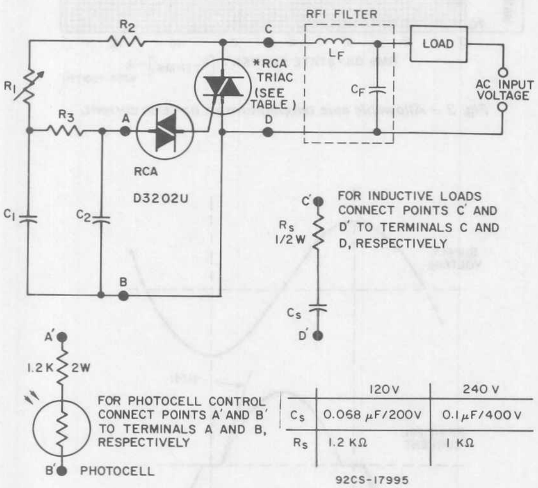


Fig. 8 — DC holding current for either direction of on-state current vs. case temperature.



	120 V	240 V
C_S	0.068 μF/200V	0.1 μF/400 V
R_S	1.2 KΩ	1 KΩ

AC INPUT VOLTAGE	C_1	C_2	R_1	R_2	R_3	RFI FILTER L_F* (typ.)	RFI FILTER C_F* (typ.)	RCA TYPES
120 V 60 Hz	0.1 μF 200 V	0.1 μF 100 V	100 KΩ ½ W	2.2 KΩ ½ W	15 KΩ ½ W	100 μH	0.1 μF 200 V	T2800B
240 V 50 Hz	0.1 μF 400 V	0.1 μF 100 V	250 KΩ 1 W	3.3 KΩ ½ W	15 KΩ ½ W	200 μH	0.1 μF 400 V	T2800D
240 V 60 Hz	0.1 μF 400 V	0.1 μF 100 V	200 KΩ 1 W	3.3 KΩ ½ W	15 KΩ ½ W	200 μH	0.1 μF 400 V	T2800D

* Typical values for lamp dimming circuits.

Fig. 9 — Typical phase-control circuit for lamp dimming, heat controls, and universal motor speed controls.

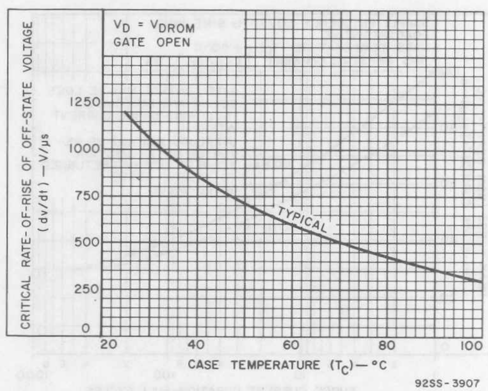


Fig. 10 — Critical rate-of-rise of off-state voltage vs. case temperature.

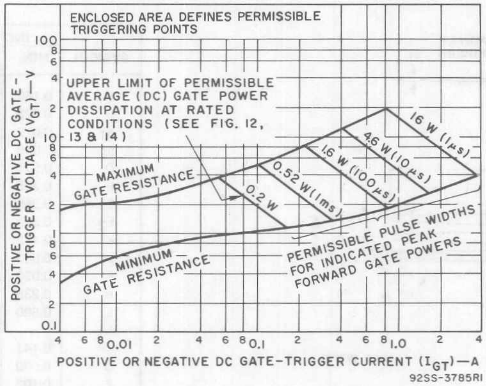


Fig. 11 — Gate pulse characteristics for all triggering modes.

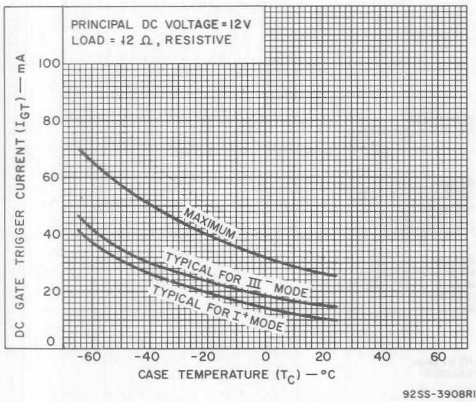


Fig. 12 — DC gate-trigger current (for I^+ and III^- triggering modes) vs. case temperature.

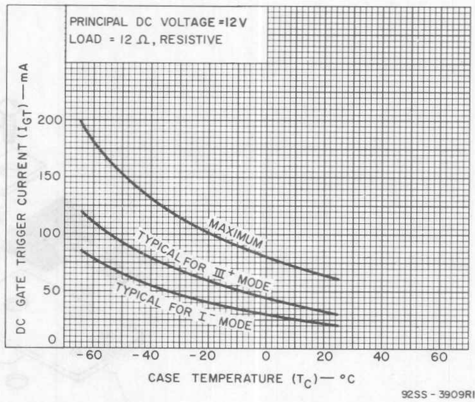


Fig. 13 — DC gate-trigger current (for I^- and III^+ triggering modes), vs. case temperature.

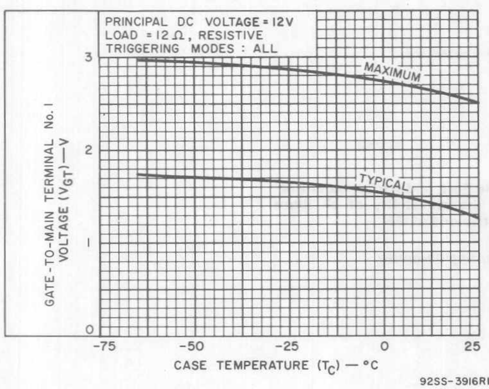


Fig. 14 — DC gate-trigger voltage vs. case temperature.

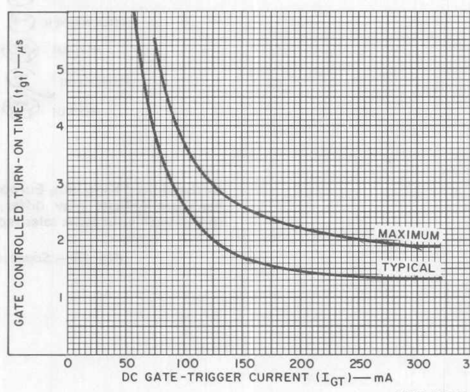
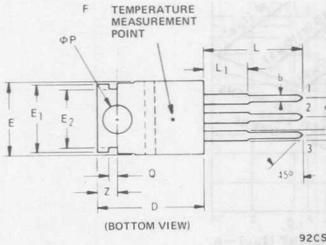
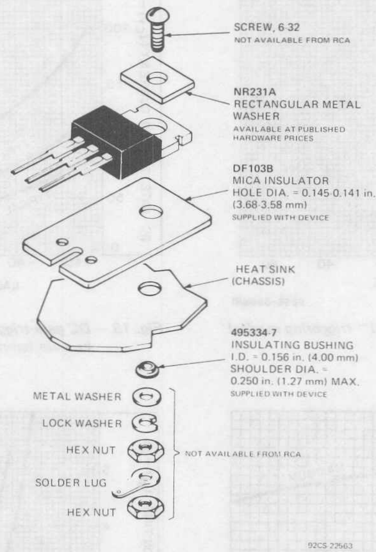


Fig. 15 — Typical turn-on time vs. gate-trigger current.



b_1	0.012	0.020	0.31	0.51
b_2	0.045	0.055	1.143	1.397
D	0.575	0.600	14.61	15.24
E	0.395	0.410	10.04	10.41
E_1	0.365	0.385	9.28	9.77
E_2	0.300	0.320	7.62	8.12
e	0.180	0.220	4.57	5.58
e_1	0.080	0.120	2.03	3.04
F	0.020	0.055	0.51	1.39
H	0.235	0.265	5.97	6.73
L	0.500	–	12.70	–
L_1	–	0.250	–	6.35
ϕP	0.141	0.145	3.582	3.683
Q	0.040	0.060	1.02	1.52
Z	0.100	0.120	2.54	3.04



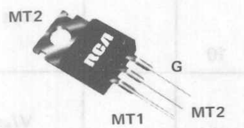
In the United Kingdom, Europe, Middle East, and Africa, mounting-hardware policies may differ; check the availability of all items shown with your RCA sales representative or supplier.

Fig. 16 – Suggested mounting hardware.

RCA
Solid State
Division

Thyristors

T2801DF



JEDEC TO-220AB

6-Ampere Silicon Triac

For Power-Control and Power-Switching Applications

Features:

- 6-A (rms) on-state current rating
- 100-A peak surge full-cycle current rating at 60 Hz
  85-A peak surge full-cycle current rating at 50 Hz
- Shorted-emitter design — contains internal diffused resistor from gate to main terminal 1
- Center gate construction — provides rapid uniform gate-current spreading for faster turn-on with substantially reduced heating effects
- Low switching losses
- Low thermal resistance
- Package suitable for mounting on printed-circuit boards

The T2801DF triac (formerly RCA type 40842) is a gate-controlled full-wave ac switch. It is intended for the control of ac loads in such applications as motor controls, light dimmers (300 to 1440 W), heating controls, and power-switching systems.

This device is designed to switch from an off-state to an on-state for either polarity of applied voltage with positive or negative gate triggering voltages. It has an on-state current rating of 6 amperes at a case temperature of 80°C and a repetitive off-state voltage rating of 450 volts.

The unique plastic package design provides not only ease of mounting but also low thermal impedance, which allows operation at high case temperatures and permits reduced heat-sink size.

MAXIMUM RATINGS, *Absolute-Maximum Values:*
For operation with 50/60 Hz, Sinusoidal Supply Voltage and Resistive or Inductive Load

		T2801DF (40842)	
REPETITIVE PEAK OFF-STATE VOLTAGE*			
Gate open, for T_J = -40 to +100°C	V_{DROM}	450	V
RMS ON-STATE CURRENT			
For case temperature (T_C) of +80°C and a conduction angle of 360°	$I_{T(RMS)}$	6	A
PEAK SURGE (NON-REPETITIVE) ON-STATE CURRENT			
For one full cycle of applied principal voltage (60-Hz, sinusoidal)	I_{TSM}	100	A
For one full cycle of applied principal voltage (50-Hz, sinusoidal)		85	A
For more than one full cycle of applied voltage		See Fig. 4	
PEAK GATE-TRIGGER CURRENT †			
For 10 μs max.	I_{GTM}	4	A
GATE POWER DISSIPATION:			
PEAK†			
For 10 μs max. and $I_{GTM} \leq 4$ A (peak)	P_{GM}	16	W
AVERAGE	$P_{G(AV)}$	0.2	W
TEMPERATURE RANGE‡			
Storage		-40 to +150°C	
Operating (case)		-40 to +100°C	

* For either polarity of main terminal 2 voltage (V_{MT2}) with reference to main terminal 1.
† For either polarity of gate voltage (V_G) with reference to main terminal 1.
‡ For information on the reference point of temperature measurement, see Dimensional Outline.

11-73

ELECTRICAL CHARACTERISTICS, *At Maximum Ratings and at Indicated Case Temperature (T_C) Unless Otherwise Specified.*

CHARACTERISTIC	SYMBOL	LIMITS MIN.	TYP.	MAX.	UNITS
Peak Off-State Current: * Gate Open At T_J = +100°C and V_{DROM} = Max. rated value	I_{DROM}	–	0.1	2	mA
Maximum On-State Voltage: * For i_T = 10 A (peak) and T_C = +25°C	v_{TM}	–	1.5	2.25	V
Critical Rate of Rise of Commutation Voltage: *♠ For v_D = V_{DROM}, $I_{T(RMS)}$ = 6 A, Commutating di/dt = 3.2 A/ms, and gate unenergized At T_C = +80°C	dv/dt	2	10	–	V/µs
Critical Rate of Rise of Off-State Voltage: * For v_D = V_{DROM}, exponential voltage rise, and gate open At T_C = +100°C For other case temperatures	dv/dt	20	250 See Fig. 6.	–	V/µs
DC Gate-Trigger Current: † For v_D = 12 V (DC), R_L = 12Ω T_C = +25°C, and specified triggering mode: I+ Mode: V_{MT2} is positive, V_G is positive III- Mode: V_{MT2} is negative, V_G is negative	I_{GT}	– –	25 30	80 80	mA
DC Gate-Trigger Voltage: *† For v_D = 12 V (DC) and R_L = 12Ω At T_C = +25°C For other case temperatures For v_D = V_{DROM} and R_L = 125Ω At T_C = +100°C	V_{GT}	– 0.2	1.5 See Fig. 10. –	4.0 –	V
Gate-Controlled, Turn-On Time: (Delay Time + Rise Time) For v_D = V_{DROM} and I_{GT} = 80 mA 0.1µs rise time, and i_T = 10 A (peak) at T_C = +25°C	t_{gt}	–	2.2	–	µs
Thermal Resistance: Junction-to-Case Junction-to-Ambient	$\theta_{J\text{-}C}$ $\theta_{J\text{-}A}$	– –	– –	2.2 60	°C/W °C/W

* For either polarity of main terminal 2 voltage (V_{MT2}) with reference to main terminal 1.
† For either polarity of gate voltage (V_G) with reference to main terminal 1.
♠ Variants of these devices having dv/dt characteristics selected specifically for inductive loads are available on special order; for additional information, contact your RCA Representative or your RCA Distributor.

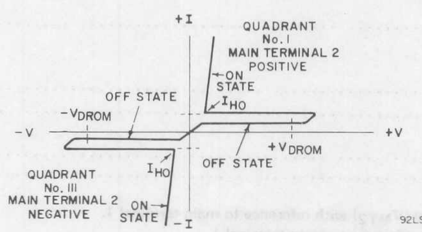


Fig. 1 – Principal voltage-current characteristic.

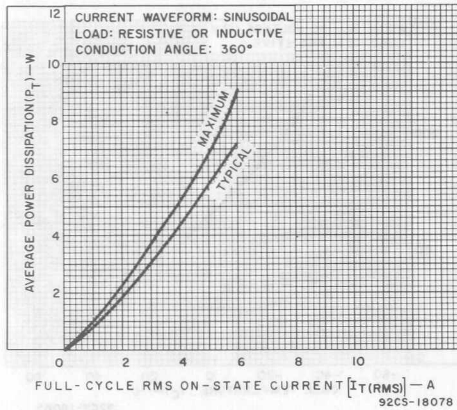


Fig. 2 — Power dissipation vs. on-state current.

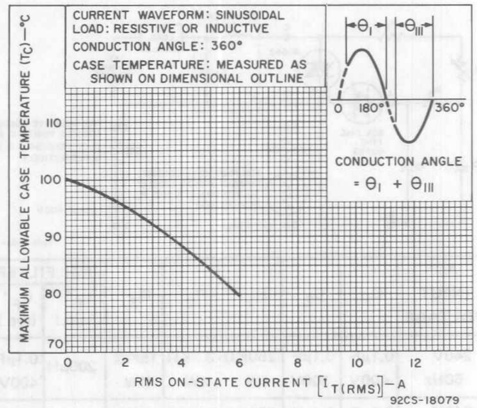


Fig. 3 — Allowable case temperature vs. on-state current.

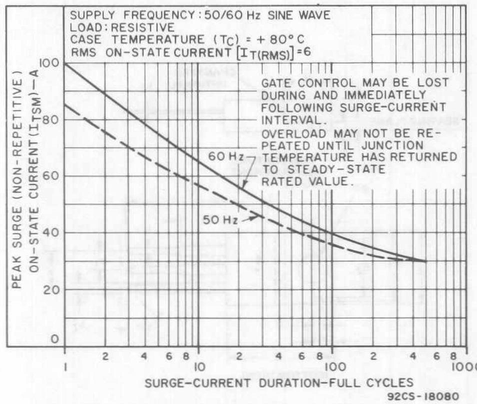


Fig. 4 — Peak surge on-state current vs. surge-current duration.

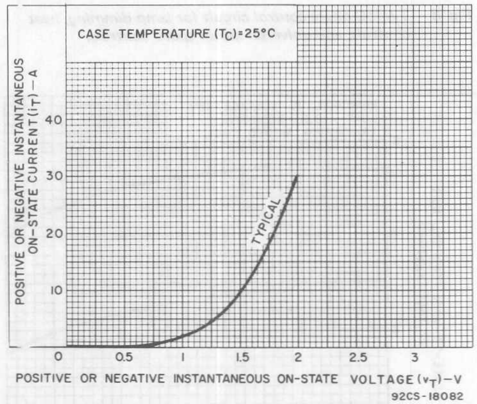


Fig. 5 — On-state current vs. on-state voltage.

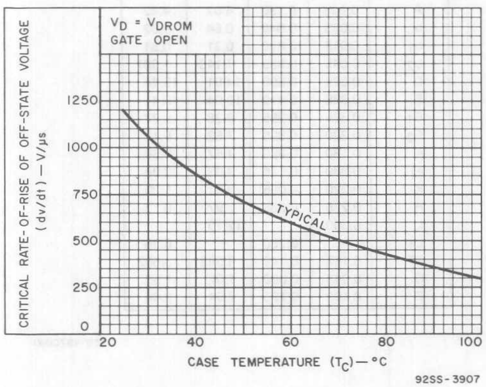


Fig. 6 — Critical rate-of-rise of off-state voltage vs. case temperature.

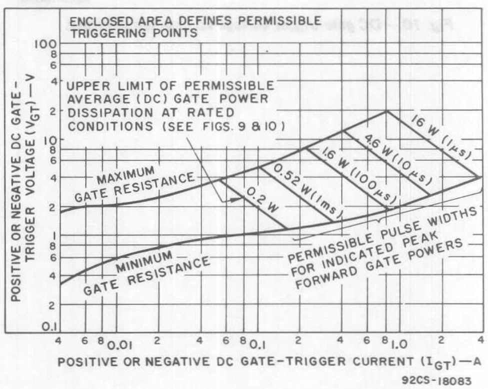
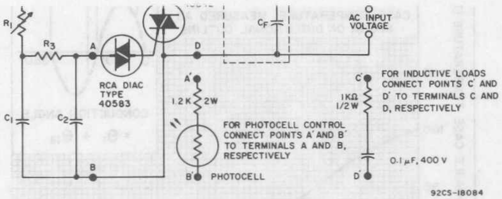


Fig. 7 — Gate pulse characteristics for all triggering modes.



AC INPUT VOLTAGE	C_1	C_2	R_1	R_2	R_3	RFI FILTER L_F* (typ.)	RFI FILTER C_F* (typ.)
240V 50Hz	0.1μF 400V	0.1μF 100V	250KΩ 1W	3.3KΩ ½W	15KΩ ½W	200μH	0.1μF 400V
240V 60Hz	0.1μF 400V	0.1μF 100V	200KΩ 1W	3.3KΩ ½W	15KΩ ½W	200μH	0.1μF 400V

*Typical values for lamp-dimming circuits.

Fig. 8 — Typical phase-control circuit for lamp dimming, heat controls, and universal-motor speed controls.

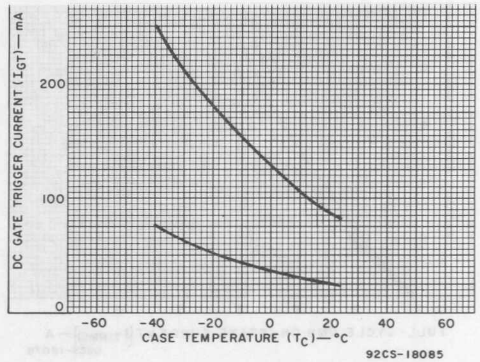


Fig. 9 — DC gate-trigger current (for I^+ and III^- triggering modes) vs. case temperature.

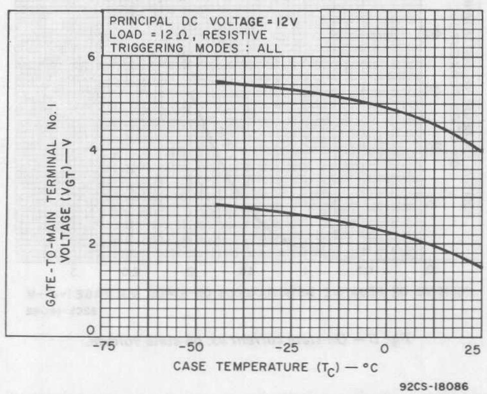
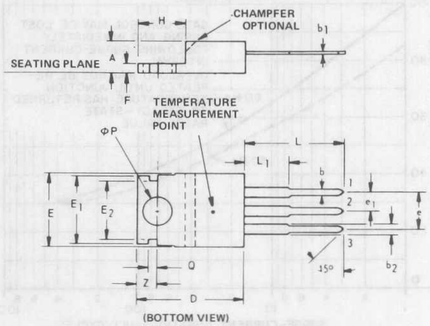


Fig. 10 — DC gate-trigger voltage vs. case temperature.



SYMBOL	INCHES MIN.	INCHES MAX.	MILLIMETERS MIN.	MILLIMETERS MAX.
A	0.160	0.190	4.07	4.82
b	0.025	0.040	0.64	1.02
b_1	0.012	0.020	0.31	0.51
b_2	0.045	0.055	1.143	1.397
D	0.575	0.600	14.61	15.24
E	0.395	0.410	10.04	10.41
E_1	0.365	0.385	9.28	9.77
E_2	0.300	0.320	7.62	8.12
e	0.180	0.220	4.57	5.58
e_1	0.080	0.120	2.03	3.04
F	0.020	0.055	0.51	1.39
H	0.235	0.265	5.97	6.73
L	0.500	–	12.70	–
L_1	–	0.250	–	6.35
ΦP	0.141	0.145	3.582	3.683
Q	0.040	0.060	1.02	1.52
Z	0.100	0.120	2.54	3.04

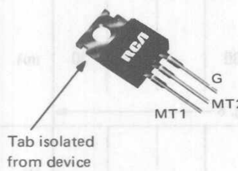
92CS-19700R1

RCA Solid State Division

Thyristors

T2850A T2850B T2850D

8-A Isolated-Tab Silicon Triacs



JEDEC TO-220AB H-1535

Three-Lead Plastic Types for
Power-Control and Power-Switching Applications

For Low-Voltage Operation – T2850A (40900)*
For 120-V Line Operation – T2850B (40901)*
For 240-V Line Operation – T2850D (40902)*

*Numbers in parentheses (e.g. 40900) are former RCA type numbers.

Features:

- **Internal Isolation**
- **100-A Peak Surge Full-Cycle Current Ratings**
- **Shorted-Emitter, Center-Gate Design**
- **Low Switching Losses**
- **Low Thermal Resistance**
- **Package Suitable for Direct Mounting on Heat Sink**
- **Glass Passivated Junctions**

The T2850A, T2850B[a], and T2850D[b] triacs are gate-controlled full-wave ac switches utilizing a plastic case with three leads to facilitate mounting on printed-circuit boards. They are intended for the control of ac loads in such applications as motor controls, light dimmers, heating controls, and power-switching systems.

These devices are designed to switch from an off-state to an on-state for either polarity of applied voltage with positive or negative gate triggering voltages. They have an on-state current rating of 8 amperes at a T_C of 75°C and repetitive off-state voltage ratings of 100, 200, and 400 volts, respectively.

The ISOWATT package uses a plastic case with three leads that are electrically isolated from the mounting flange. Because of this internal isolation, the triac can be mounted directly on a heat sink, without any insulating hardware; therefore heat transfer is improved and heat-sink size can be reduced.

[a]Formerly RCA Dev. No. TA8357
[b]Formerly RCA Dev. No. TA8358

MAXIMUM RATINGS, *Absolute-Maximum Values:*
For Operation with Sinusoidal Supply Voltage at Frequencies up to 50/60 Hz and with Resistive or Inductive Load.

		T2850A	T2850B	T2850D	
REPETITIVE PEAK OFF-STATE VOLTAGE:•					
Gate open, T_J = –65 to 100°C	V_{DROM}	100	200	400	V
RMS ON-STATE CURRENT (Conduction angle = 360°):					
Case temperature	$I_{T(RMS)}$				
T_C = 75°C			8		A
For other conditions			See *Fig. 3*		
PEAK SURGE (NON-REPETITIVE) ON-STATE CURRENT:					
For one cycle of applied principal voltage	I_{TSM}				
60 Hz (sinusoidal)			100		A
50 Hz (sinusoidal)			85		A
For more than one cycle of applied principal voltage			See *Fig. 4*		
PEAK GATE-TRIGGER CURRENT: ▪					
For 1 μs max.; see *Fig. 11*	I_{GTM}		4		A
GATE POWER DISSIPATION:					
Peak (For 1 μs max., $I_{GTM} \leq$ 4 A; see *Fig. 11*)	P_{GM}		16		W
AVERAGE	$P_{G(AV)}$		0.2		W
TEMPERATURE RANGE: ▲					
Storage	T_{stg}		–65 to 150		°C
Operating (Case)	T_C		–65 to 100		°C
TERMINAL TEMPERATURE (During soldering):					
For 10 s max. (terminals and case)	T_T		225		°C

• For either polarity of main terminal 2 voltage (V_{MT2}) with reference to main terminal 1.

▪ For either polarity of gate voltage (V_G) with reference to main terminal 1

▲ For temperature measurement reference point, see *Dimensional Outline.*

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ELECTRICAL CHARACTERISTICS *At Maximum Ratings Unless Otherwise Specified, and at Indicated Case Temperature (T_C)*

CHARACTERISTIC	SYMBOL	LIMITS T2850A MIN.	T2850A TYP.	T2850A MAX.	T2850B MIN.	T2850B TYP.	T2850B MAX.	T2850D MIN.	T2850D TYP.	T2850D MAX.	UNITS
Peak Off-State Current:* Gate Open, V_{DROM} = Max. rated value At T_J = 100°C	I_{DROM}	–	0.1	2	–	0.1	2	–	0.1	2	mA
Maximum On-State Voltage:* For i_T = 30 A (peak) and T_C = 25°C	v_{TM}	–	1.7	2	–	1.7	2	–	1.7	2	V
DC Holding Current:* Gate Open Initial principal current = 150 mA (dc) At T_C = 25°C	I_{HO}	–	15	30	–	15	30	–	15	30	mA
For other case temperatures		See Fig. 8									
Critical Rate of Rise of Commutation Voltage:*♣ For v_D = V_{DROM}, $I_{T(RMS)}$ = 8 A, Commutating di/dt = 4.3 A/ms, and gate unenergized At T_C = 75°C	dv/dt	4	10	–	4	10	–	4	10	–	V/µs
Critical Rate of Rise of Off-State Voltage:* For v_D = V_{DROM}, exponential voltage rise, and gate open At T_C = 100°C	dv/dt	125	350	–	100	300	–	75	250	–	V/µs
For other case temperatures		See Fig. 10									
DC Gate-Trigger Current:*† For v_D = 12 V (dc), R_L = 12Ω T_C 25°C, and specified triggering mode: I⁺ Mode: V_{MT2} is positive, V_G is positive	I_{GT}	–	10	25	–	10	25	–	10	25	mA
III⁻ Mode: V_{MT2} is negative, V_G is negative		–	15	25	–	15	25	–	15	25	
I⁻ Mode: V_{MT2} is positive, V_G is negative		–	20	60	–	20	60	–	20	60	
III⁺ Mode: V_{MT2} is negative, V_G is positive		–	30	60	–	30	60	–	30	60	
For other case temperatures		See Figs. 12 & 13									
DC Gate-Trigger Voltage:*† For v_D = 12 V (dc) and R_L = 12Ω At T_C = 25°C	V_{GT}	–	1.25	2.5	–	1.25	2.5	–	1.25	2.5	V
For other case temperatures		See Fig. 14									
For v_D = V_{DROM} and R_L = 125Ω At T_C = 100°C		0.2	–	–	0.2	–	–	0.2	–	–	
Gate-Controlled Turn-On Time (Delay Time + Rise Time): For v_D = V_{DROM} and I_{GT} = 160 mA rise time = 0.1 µs, and i_T = 10 A (peak) At T_C = 25°C *(See Fig. 15)*	t_{gt}	–	1.6	2.5	–	1.6	2.5	–	1.6	2.5	µs
Thermal Resistance: Junction-to-Case	$R_{\theta JC}$	–	–	3.1	–	–	3.1	–	–	3.1	°C/W
Junction-to-Ambient	$R_{\theta JA}$	–	–	60	–	–	60	–	–	60	°C/W

*For either polarity of main terminal 2 voltage (V_{MT2}) with reference to main terminal 1.

†For either polarity of gate voltage (V_G) with reference to main terminal 1.

♣Variants of these devices having dv/dt characteristics selected specifically for inductive loads are available on special order; for additional information, contact your RCA Representative or your RCA Distributor.

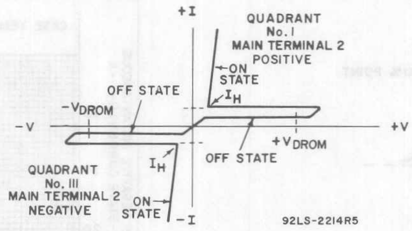


Fig. 1 — Principal voltage-current characteristic.

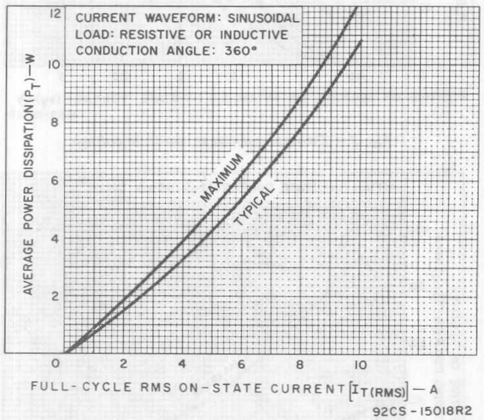


Fig. 2 — Power dissipation vs. on-state current.

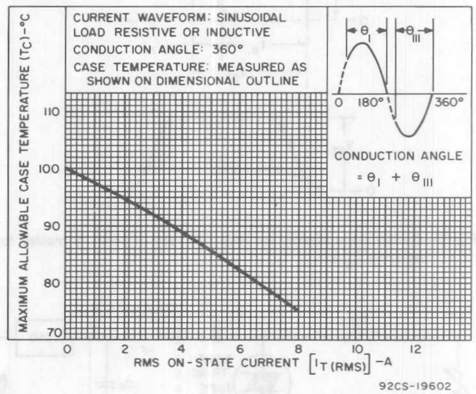


Fig. 3 — Allowable case temperature vs. on-state current.

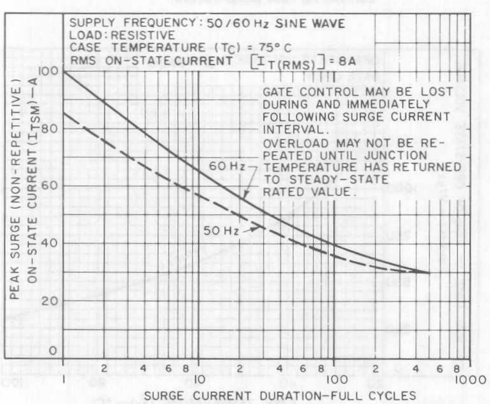


Fig. 4 — Peak surge on-state current vs. surge current duration.

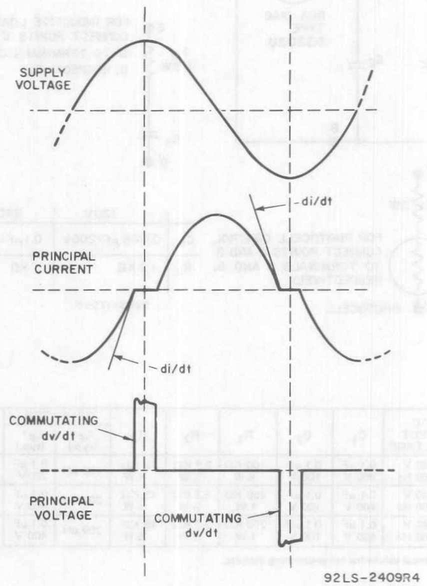


Fig. 5 — Oscilloscope display of commutating dv/dt.

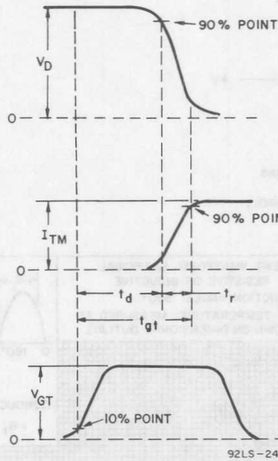


Fig. 6—Oscilloscope display for measurement of gate-controlled turn-on time (t_{gt}).

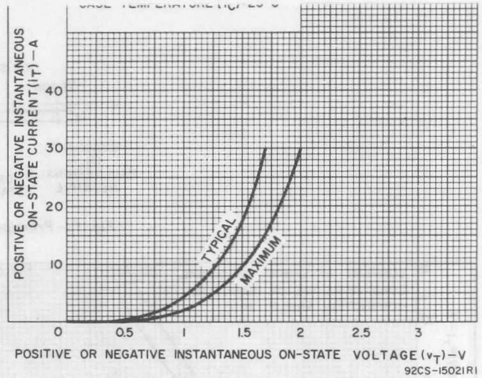


Fig. 7 — On-state current vs. on-state voltage.

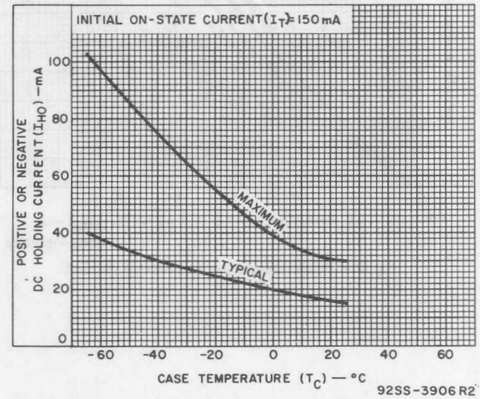
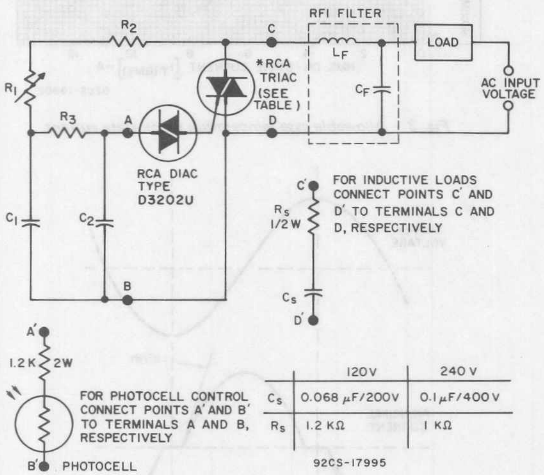


Fig. 8—DC holding current for either direction of on-state current vs. case temperature.



	120V	240 V
C_s	0.068 μF/200V	0.1 μF/400 V
R_s	1.2 KΩ	1 KΩ

AC INPUT VOLTAGE	C_1	C_2	R_1	R_2	R_3	RFI FILTER L_F* (typ.)	RFI FILTER C_F* (typ.)	RCA TYPES
120 V 60 Hz	0.1 μF 200 V	0.1 μF 100 V	100 KΩ ½ W	2.2 KΩ ½ W	15 KΩ ½ W	100 μH	0.1 μF 200V	T2850B
240 V 50 Hz	0.1 μF 400 V	0.1 μF 100 V	250 KΩ 1 W	3.3 KΩ ½ W	15 KΩ ½ W	200 μH	0.1 μF 400 V	T2850D
240 V 60 Hz	0.1 μF 400 V	0.1 μF 100 V	200 KΩ 1 W	3.3 KΩ ½ W	15 KΩ ½ W	200 μH	0.1 μF 400 V	T2850D

*Typical values for lamp-dimming circuits.

Fig. 9—Typical phase-control circuit for lamp dimming, heat controls, and universal motor speed controls.

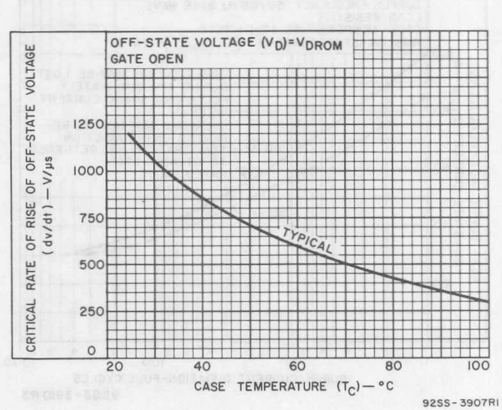


Fig. 10—Critical rate of rise of off-state voltage vs. case temperature.

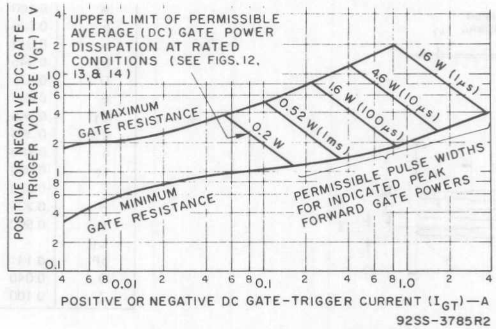


Fig. 11 — Gate-pulse characteristics for all triggering modes.

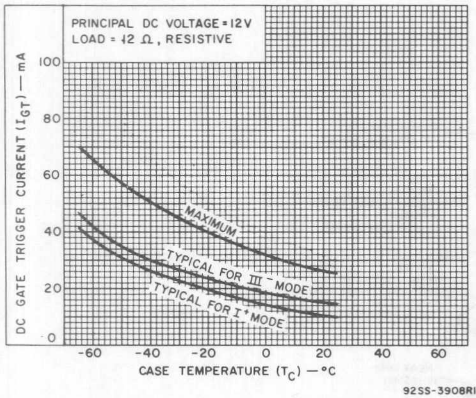


Fig. 12—DC gate-trigger current (for I^+ and III^- triggering modes) vs. case temperature.

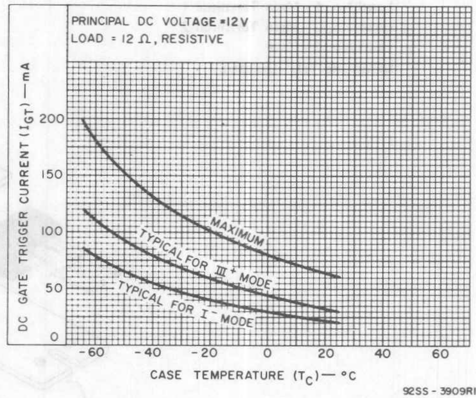


Fig. 13—DC gate-trigger current for I^- and III^+ triggering modes) vs. case temperature.

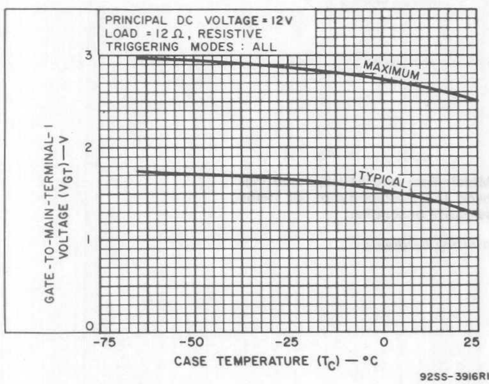


Fig. 14 — DC gate-trigger voltage vs. case temperature.

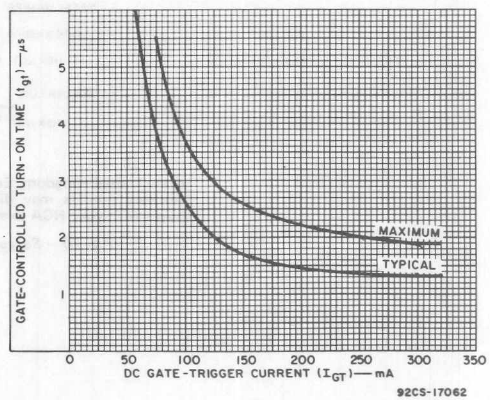
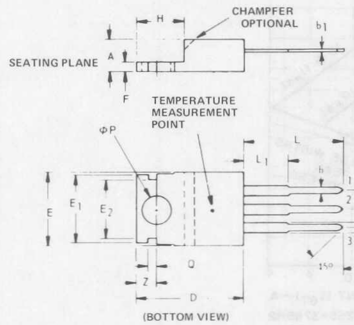


Fig. 15 — Typical turn-on time vs. gate-trigger current.

DIMENSIONAL OUTLINE

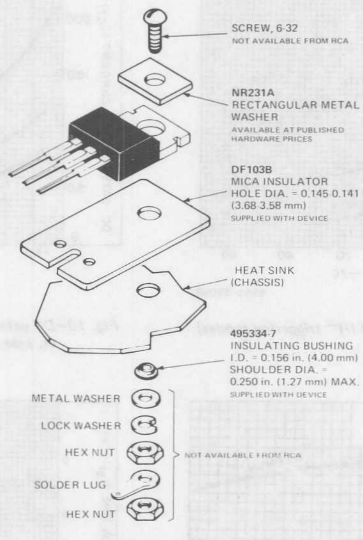


92CS-19700R1

SYMBOL	INCHES MIN.	INCHES MAX.	MILLIMETERS MIN.	MILLIMETERS MAX.
A	0.160	0.190	4.07	4.82
b	0.025	0.040	0.64	1.02
b_1	0.012	0.020	0.31	0.51
b_2	0.045	0.055	1.143	1.397
D	0.575	0.600	14.61	15.24
E	0.395	0.410	10.04	10.41
E_1	0.365	0.385	9.28	9.77
E_2	0.300	0.320	7.62	8.12
e	0.180	0.220	4.57	5.58
e_1	0.080	0.120	2.03	3.04
F	0.020	0.055	0.51	1.39
H	0.235	0.265	5.97	6.73
L	0.500	-	12.70	–
L_1	-	0.250	–	6.35
ϕP	0.141	0.145	3.582	3.683
Q	0.040	0.060	1.02	1.52
Z	0.100	0.120	2.54	3.04

TERMINAL CONNECTIONS

Lead No. 1 - Main Terminal 1
Lead No. 2 - Main Terminal 2
Lead No. 3 - Gate
Mounting Tab - Isolated



In the United Kingdom, Europe, Middle East, and Africa, mounting-hardware policies may differ; check the availability of all items shown with your RCA sales representative or supplier.

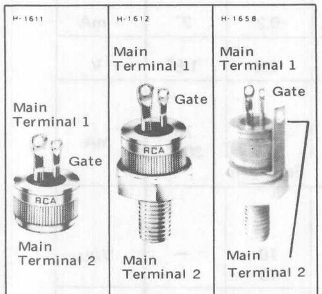
Fig. 16 – Suggested mounting hardware.

File No. 458

RCA
Solid State
Division

Thyristors

2N5571 2N5573 T4120B 2N5572 2N5574 T4120D T4100M T4110M T4120M



2N5571 2N5572 T4100M Press-fit	2N5573 2N5574 T4110M Stud	T4120B T4120D T4120M Isolated-stud

15-A Silicon Triacs

Press-Fit, Stud, and Isolated-Stud Type Packages

For 120-V Line Operation – 2N5571, 2N5573, T4120B (40802)**
For 240-V Line Operation – 2N5572, 2N5574, T4120D (40803)**
For High-Voltage Operation – T4100M, T4110M, T4120M (40797, 40798, 40804)**

**Numbers in parentheses (e.g. 40802) are former RCA type numbers.

Features:

- di/dt Capability = 150 A/μs
- Shorted-Emitter Center-Gate Design
- Low Switching Losses
- Low On-State Voltage at High Current Levels
- Low Thermal Resistance

These RCA triacs are gate-controlled, full-wave silicon ac switches. They are designed to switch from an off-state to an on-state for either polarity of applied voltage with positive or negative gate triggering voltages.

These triacs are intended for control of ac loads in applications such as heating controls, motor controls, arc-welding equipment, light dimmers, and power switching systems.

MAXIMUM RATINGS, *Absolute-Maximum Values:*
For Operation with Sinusoidal Supply Voltage at Frequencies up to 50/60 Hz and with Resistive or Inductive Load.

		2N5571 2N5573 T4120B	2N5572 2N5574 T4120D	T4100M T4110M T4120M	
***REPETITIVE PEAK OFF-STATE VOLTAGE:●**					
Gate open, T_J = –65 to 100° C	V_{DROM}	200	400	600	V
***RMS ON-STATE CURRENT (Conduction angle = 360°):**	$I_{T(RMS)}$				
Case temperature					
T_C = 80° C (Press-fit & stud types)			15		A
= 75° C (Isolated-stud types)			15		A
For other conditions			See *Fig. 3*		
PEAK SURGE (NON-REPETITIVE) ON-STATE CURRENT:	I_{TSM}				
For one cycle of applied principal voltage					
* 60 Hz (sinusoidal)			100		A
50 Hz (sinusoidal)			85		A
For more than one cycle of applied principal voltage			See *Fig. 4*		
RATE-OF-CHANGE OF ON-STATE CURRENT:	di/dt				
$V_{DM} = V_{DROM}$, I_{GT} = 160 mA, t_r = 0.1 μs (See *Fig. 13)*			150		A/μs
PEAK GATE-TRIGGER CURRENT:■	I_{GTM}				
For 1 μs max., See *Fig. 7*			4		A
***GATE POWER DISSIPATION:**					
PEAK (For 1 μs max., $I_{GTM} \leq$ 4 A, See *Fig. 7)*	P_{GM}		16		W
AVERAGE	$P_{G(AV)}$		0.5		W
***TEMPERATURE RANGE:▲**					
Storage	T_{stg}		–65 to 150		°C
Operating (Case)	T_C		–65 to 100		°C
***TERMINAL TEMPERATURE (During soldering):**	T_T				
For 10 s max. (terminals and case)			225		°C

* In accordance with JEDEC registration data format (JS-14, RDF 2) filed for the JEDEC 2N-Series) types.
● For either polarity of main terminal 2 voltage (V_{MT2}) with reference to main terminal 1.
■ For either polarity of gate voltage (V_G) with reference to main terminal 1.
▲ For temperature measurement reference point, see Dimensional Outline.

11-73

CHARACTERISTIC	SYMBOL	LIMITS For All Types Unless Otherwise Specified			UNITS
		Min.	Typ.	Max.	
Peak Off-State Current:♠ Gate open, $T_J = 100^oC$, V_{DROM} = Max. rated value	I_{DROM}	–	0.2	2*	mA
Maximum On-State Voltage:♠ For i_T = 21 A (peak), $T_C = 25^oC$	V_{TM}	–	1.4	1.8*	V
DC Holding Current:♠ Gate open, Initial principal current = 500 mA (DC), v_D = 12V:					
$T_C = 25^oC$	I_{HO}	–	20	75	mA
$T_C = -65^oC$		–	75	300*	
For other case temperatures			See *Fig. 6*		
Critical Rate-of-Rise of Commutation Voltage:♠ For $v_D = V_{DROM}$, $I_{T(RMS)}$ = 15 A, commutating di/dt = 8 A/ms, gate unenergized, (See *Fig. 14*):					
$T_C = 80^oC$ (Press-fit & stud types)	dv/dt	2*	10	–	V/µs
= 75^oC (Isolated-stud)		2	10		
Critical Rate-of-Rise of Off-State Voltage:♠ For $v_D = V_{DROM}$, exponential voltage rise, gate open, $T_C = 100^oC$:					
2N5571, 2N5573, T4120B		30*	150	–	
2N5572, 2N5574, T4120D	dv/dt	20*	100	–	V/µs
T4100M, T4110M, T4120M		10	75	–	
DC Gate-Trigger Current:♠♦ Mode V_{MT2} V_G					
For v_D = 12 V (DC), I^+ positive positive		–	20	50	
$R_L = 30\ \Omega$, III^- negative negative		–	20	50	
$T_C = 25^oC$ I^- positive negative		–	35	80	
III^+ negative positive		–	35	80	
Mode V_{MT2} V_G	I_{GT}				mA
For v_D = 12 V (DC), I^+ positive positive		–	75	150*	
$R_L = 30\ \Omega$, III^- negative negative		–	75	150*	
$T_C = -65^oC$ I^- positive negative		–	100	200*	
III^+ negative positive		–	100	200*	
For other case temperatures			See *Figs. 8 & 9*		
DC Gate-Trigger Voltage:♠♦ For v_D = 12 V(DC), $R_L = 30\ \Omega$,					
$T_C = 25^oC$		–	1	2.5	
$T_C = -65^oC$	V_{GT}	–	2	4*	V
For other case temperatures			See *Fig. 10*		
For $v_D = V_{DROM}$, $R_L = 125\ \Omega$, $T_C = 100^oC$		0.2	–	–	
Gate-Controlled Turn-On Time: (Delay Time + Rise Time) For $v_D = V_{DROM}$, I_{GT} = 160 mA, t_r = 0.1 µs, i_T = 25 A (peak), $T_C = 25^oC$ (See *Figs. 11 & 15*)	t_{gt}	–	1.6	2.5	µs
Thermal Resistance: **Junction-to-Case:**					
Steady-State	$R_{\theta JC}$	–	–	1*	
Transient			See *Fig. 12*		$^oC/W$
Junction-to-Isolated Hex (Stud, see Dim. Outline): Steady-State	$R_{\theta JIH}$	–	–	1.1	

* In accordance with JEDEC registration data format (JS-14, RDF 2) filed for the JEDEC (2N-Series) types.

♠ For either polarity of main terminal 2 voltage (V_{MT2}) with reference to main terminal 1.

♦ For either polarity of gate voltage (V_G) with reference to main terminal 1.

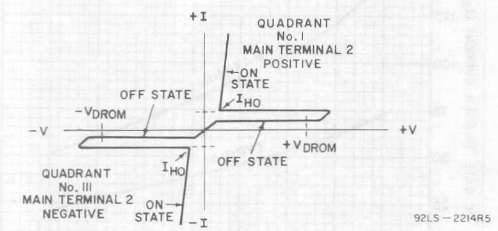


Fig. 1 – Principal voltage-current characteristic.

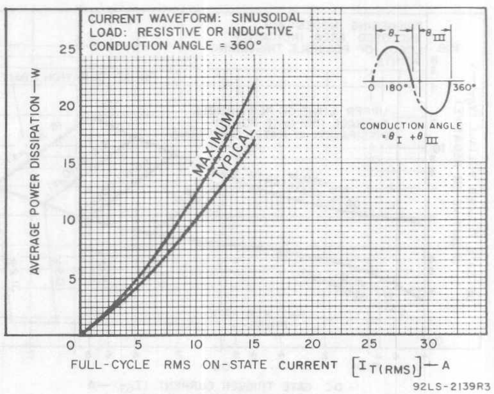


Fig. 2 – Power dissipation vs. on-state current.

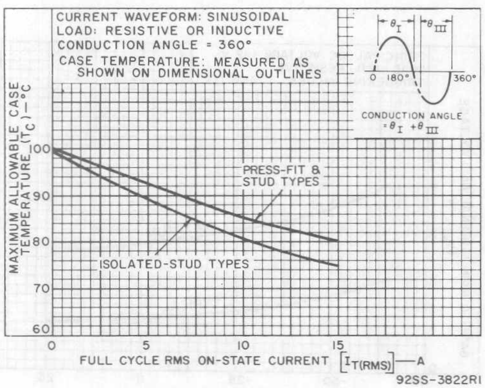


Fig. 3 – Maximum allowable case temperature vs. on-state current.

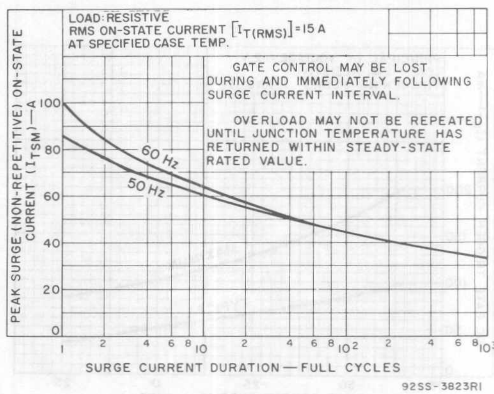


Fig. 4 – Peak surge on-state current vs. surge current duration.

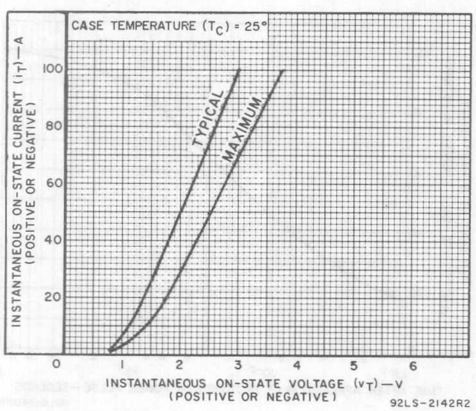


Fig. 5 – On-state current vs. on-state voltage.

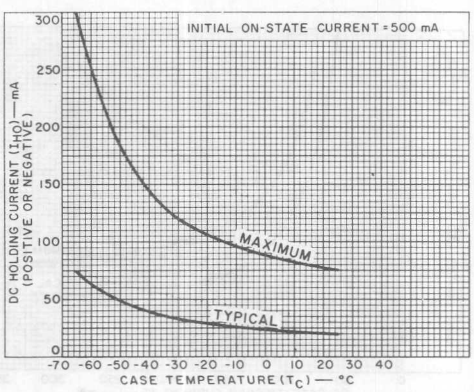


Fig. 6 – DC holding current vs. case temperature.

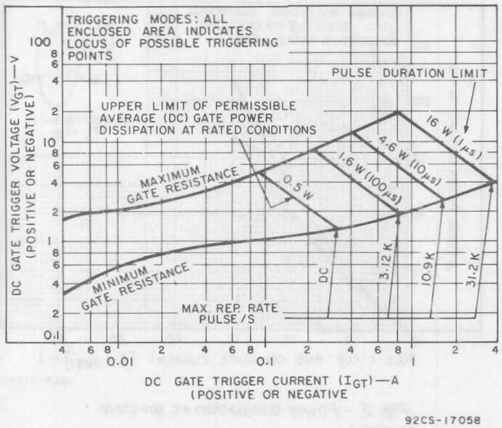


Fig. 7 – Gate trigger characteristics and limiting conditions for determination of permissible gate trigger pulses.

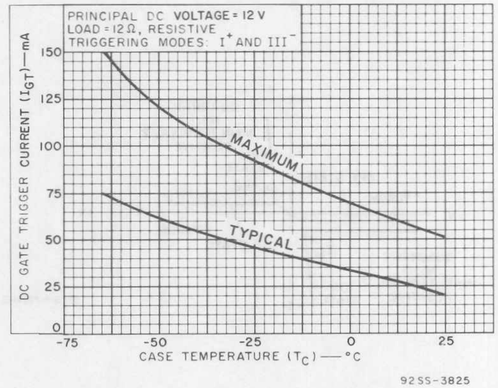


Fig. 8 – DC gate-trigger current vs. case temperature (I^+ & III^- modes).

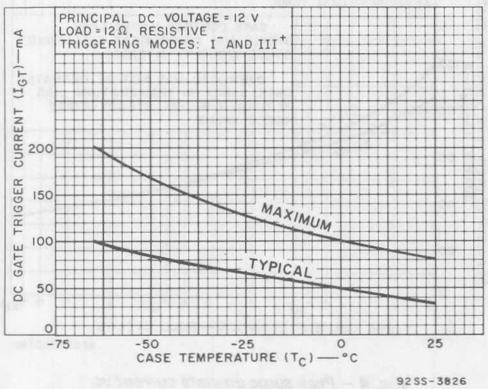


Fig. 9 – DC gate-trigger current vs. case temperature (I^- & III^+ modes).

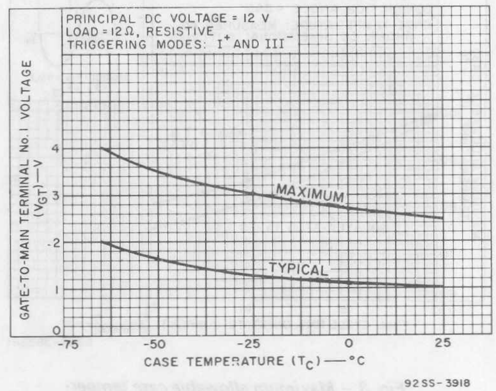


Fig. 10 – DC gate-trigger voltage vs. case temperature.

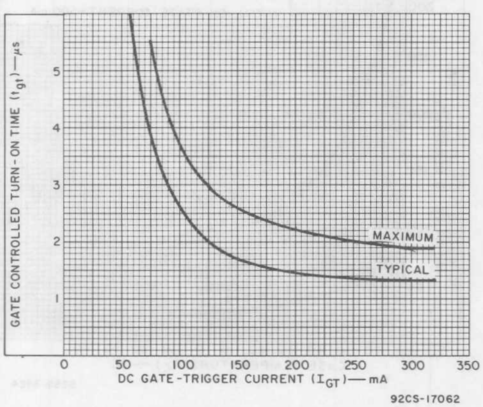


Fig. 11 – Turn-on time vs. gate trigger current.

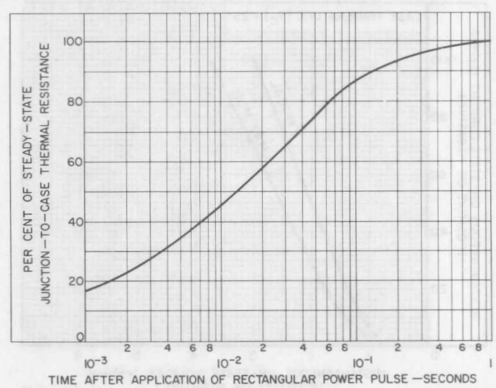


Fig. 12 – Transient junction-to-case thermal resistance vs. time.

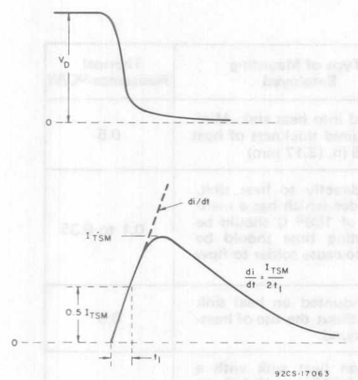


Fig. 13—Rate-of-change of on-state current with time (defining di/dt).

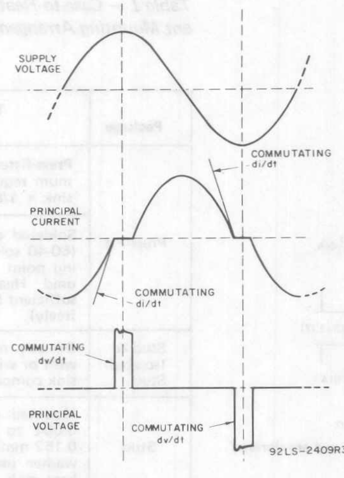


Fig. 14—Relationship between supply voltage and principal current (inductive load) showing reference points for definition of commutating voltage (dv/dt).

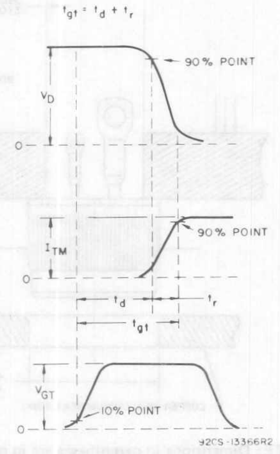


Fig. 15—Relationship between off-state voltage, on-state current, and gate-trigger voltage showing reference points for definition of turn-on time (t_{gt}).

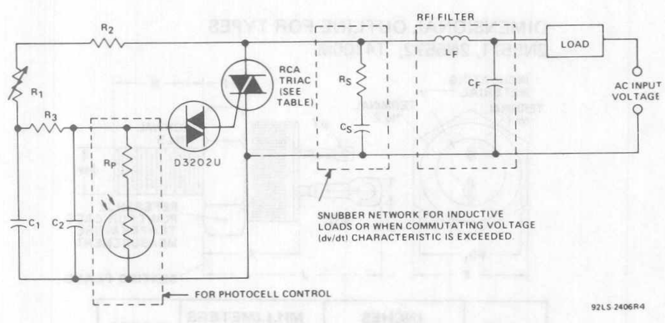


Fig. 16—Typical phase-control circuit for lamp dimming, heat control, and universal-motor speed control.

AC INPUT VOLTAGE		120V 60Hz	240V 60Hz	240V 50Hz
C_1		0.1μF 200V	0.1μF 400V	0.1μF 400V
C_2		0.1μF 100V	0.1μF 100V	0.1μF 100V
R_1		100KΩ 1/2W	200KΩ 1W	250KΩ 1W
R_2		2.2KΩ 1/2W	3.3KΩ 1/2W	3.3KΩ 1/2W
R_3		15KΩ 1/2W	15KΩ 1/2W	15KΩ 1/2W
PHOTOCELL CONTROL	R_P	1.2KΩ 2W	1.2KΩ 2W	1.2KΩ 2W
SNUBBER NETWORK	C_S	0.1 μF 200V	0.1μF 400V	0.1μF 400V
	R_S	100Ω 1/2W	100Ω 1/2W	100Ω 1/2W
RFI FILTER	C_F*	0.1μF 200V	0.1μF 400V	0.1μF 400V
	L_F*	100μH	200μH	200μH
RCA TRIACS		2N5567 2N5569 T4120B	2N5568 2N5570 T4120D	2N5568 2N5570 T4120D

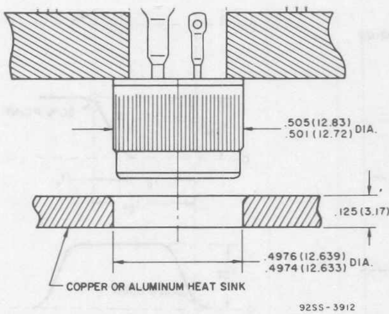
*Typical values for lamp dimming circuits.

MOUNTING CONSIDERATIONS

Mounting of press-fit package types depends upon an interference fit between the thyristor case and the heat sink. As the thyristor is forced into the heat-sink hole, metal from the heat sink flows into the knurl voids of the thyristor case. The resulting close contact between the heat sink and the thyristor case assures low thermal and electrical resistances.

A recommended mounting method, shown in *Fig. 17*, shows press-fit knurl and heat-sink hole dimensions. If these dimensions are maintained, a "worst-case" condition of 0.0085 in. (0.2159 mm) interference fit will allow press-fit insertion below the maximum allowable insertion force of 800 pounds. A slight chamfer in the heat-sink hole will help center and guide the press-fit package properly into the heat sink. The insertion tool should be a hollow shaft having an inner diameter of 0.380 ± 0.010 in. (9.65 ± 0.254 mm) and an outer diameter of 0.500 in. (12.70 mm). These dimensions provide sufficient clearance for the leads and assure that no direct force will be applied to the glass seal of the thyristor.

The press-fit package is not restricted to a single mounting arrangement; direct soldering and the use of epoxy adhesives have been successfully employed. The press-fit case is tin-plated to facilitate direct soldering to the heat sink. A 60-40 solder should be used and heat should be applied only long enough to allow the solder to flow freely.

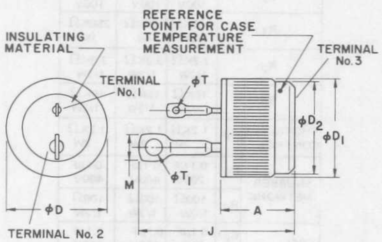


NOTE: Dimensions in parentheses are in millimeters and are derived from the basic inch dimensions as indicated.

Fig. 17—Suggested mounting method for press-fit package types.

Package	Employed	Resistance-°C/W
Press-Fit	Press-fitted into heat sink. Minimum required thickness of heat sink = 1/8 in. (3.17 mm)	0.5
	Soldered directly to heat sink. (60-40 solder which has a melting point of 188° C should be used. Heating time should be sufficient to cause solder to flow freely).	0.1 to 0.35
Stud & Isolated-Stud	Directly mounted on heat sink with or without the use of heat-sink compound.	0.6
Stud	Mounted on heat sink with a 0.004 to 0.006 in. (0.102 to 0.152 mm) thick mica insulating washer used between unit and heat sink.	
	Without heat sink compound	2.5
	With heat sink compound	1.5

DIMENSIONAL OUTLINE FOR TYPES 2N5573, 2N5574, T4110M

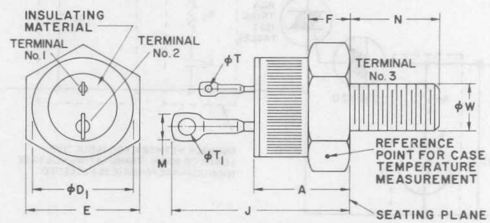


SYMBOL	INCHES		MILLIMETERS		NOTES
	MIN.	MAX.	MIN.	MAX.	
A	–	.380	–	9.65	
ϕD	.501	.510	12.73	12.95	
ϕD_1	–	.505	–	12.83	2
ϕD_2	.465	.475	11.81	12.07	
J	–	.750	–	19.05	
M	–	.155	–	3.94	1
ϕT	.058	.068	1.47	1.73	
ϕT_1	.080	.090	2.03	2.29	

NOTE 1: Contour and angular orientation of these terminals is optional.

NOTE 2: Outer diameter of knurled surface. 92SS-3816

DIMENSIONAL OUTLINE FOR TYPES 2N5571, 2N5572, T4100M

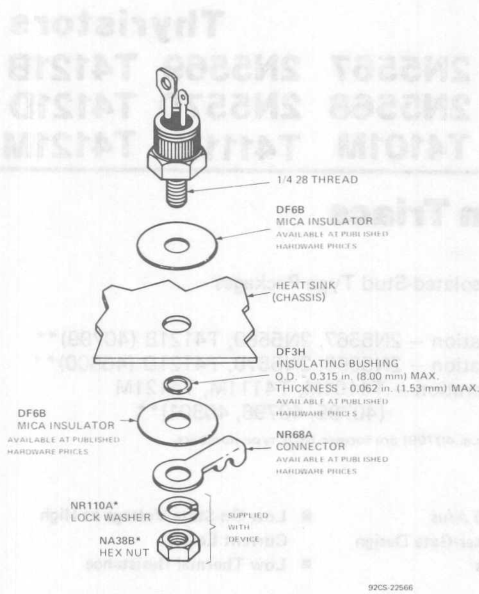


SYMBOL	INCHES		MILLIMETERS		NOTES
	MIN.	MAX.	MIN.	MAX.	
A	.330	.505	8.4	12.8	–
ϕD_1	–	.544	–	13.81	–
E	.544	.562	13.82	14.28	–
F	.113	.200	2.87	5.08	3
J	–	.950	–	24.13	–
M	–	.155	–	3.94	1
N	.422	.453	10.72	11.50	–
ϕT	.058	.068	1.47	1.73	–
ϕT_1	.080	.090	2.03	2.29	–
ϕW	.2225	.2268	5.652	5.760	2

NOTE 1: Contour and angular orientation of these terminals is optional.

NOTE 2: Pitch diameter of 1/4-28 UNF-2A (coated) threads (ASA B1. 1-1960).

NOTE 3: A chamfer or undercut on one or both ends of hexagonal portion is optional. 92SS-3817



* Only hardware required for isolated stud package.

In the United Kingdom, Europe, Middle East, and Africa, mounting-hardware policies may differ; check the availability of all items shown with your RCA sales representative or supplier.

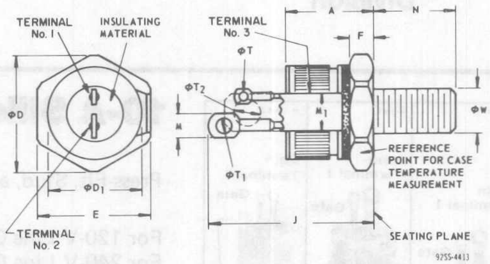
Fig. 18—Suggested mounting arrangement for stud and isolated-stud package types.

WARNING:
The RCA isolated-stud package thyristors should be handled with care. The ceramic portion of these thyristors contains BERYLLIUM OXIDE as a major ingredient. Do not crush, grind, or abrade these portions of the thyristors because the dust resulting from such action may be hazardous if inhaled.

TERMINAL CONNECTIONS

Terminal No.1—Gate
Terminal No.2—Main Terminal 1
Case, Terminal No.3—Main Terminal 2

DIMENSIONAL OUTLINE FOR TYPES T4120B, T4120D, T4120M



SYMBOL	INCHES		MILLIMETERS		NOTES
	MIN.	MAX.	MIN.	MAX.	
A	–	.673	–	17.09	
ϕD	.604	.614	15.34	15.59	
ϕD_1	.501	.505	12.72	12.82	
E	.551	.557	13.99	14.14	
F	.175	.185	4.44	4.69	
J	–	1.055	–	26.79	
M	–	.155	–	3.94	
M_1	.200	.210	5.08	5.33	
N	.422	.452	10.72	11.48	
ϕT	.058	.068	1.47	1.73	2
ϕT_1	.080	.090	2.03	2.29	2
ϕT_2	.138	.148	3.50	3.75	2
ϕW	.225	.2268	5.652	5.760	3

NOTE 1: Ceramic between hex (stud) and terminal No.3 is beryllium oxide.

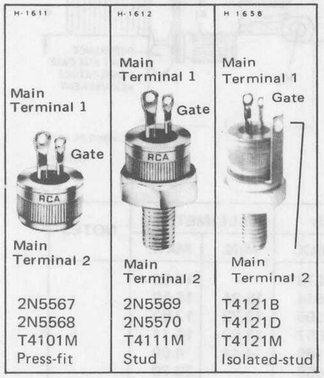
NOTE 2: Contour and angular orientation of these terminals is optional.

NOTE 3: Pitch diameter of 1/4-28 UNF-2A (coated) threads (ASA B1. 1-1960).

RCA
Solid State
Division

Thyristors

2N5567 2N5569 T4121B
2N5568 2N5570 T4121D
T4101M T4111M T4121M



10-A Silicon Triacs

Press-Fit, Stud, and Isolated-Stud Type Packages

For 120-V Line Operation – 2N5567, 2N5569, T4121B (40799)**
For 240-V Line Operation – 2N5568, 2N5570, T4121D (40800)**
For High-Voltage Operation – T4101M, T4111M, T4121M (40795, 40796, 40801)**

**Numbers in parentheses (e.g. 40799) are former RCA type numbers.

Features:

- **di/dt Capability = 150 A/μs**
- **Shorted-Emitter, Center-Gate Design**
- **Low Switching Losses**
- **Low On-State Voltage at High Current Levels**
- **Low Thermal Resistance**

These RCA triacs are gate-controlled, full-wave silicon ac switches. They are designed to switch from an off-state to an on-state for either polarity of applied voltage with positive or negative gate triggering voltages.

These triacs are intended for control of ac loads in applications such as heating controls, motor controls, arc-welding equipment, light dimmers, and power switching systems.

MAXIMUM RATINGS, *Absolute-Maximum Values:*
For Operation with Sinusoidal Supply Voltage at Frequencies up to 50/60 Hz and with Resistive or Inductive Load.

		2N5567 2N5569 T4121B	2N5568 2N5570 T4121D	T4101M T4111M T4121M	
***REPETITIVE PEAK OFF-STATE VOLTAGE:●**					
Gate open, T_J = −65 to 100°C	V_{DROM}	200	400	600	V
***RMS ON-STATE CURRENT (Conduction angle = 360°):**					
Case temperature (T_C) = 85° C	$I_{T(RMS)}$		10		A
For other conditions			See *Fig. 3*		
PEAK SURGE (NON-REPETITIVE) ON-STATE CURRENT:	I_{TSM}				
For one cycle of applied principal voltage					
* 60 Hz (sinusoidal)			100		A
50 Hz (sinusoidal)			85		A
For more than one cycle of applied principal voltage			See *Fig. 4*		
RATE-OF-CHANGE OF ON-STATE CURRENT:	di/dt				
$V_{DM} = V_{DROM}$, I_{GT} = 160 mA, t_r = 0.1 μs (See *Fig. 13*)			150		A/μs
PEAK GATE-TRIGGER CURRENT:■	I_{GTM}				
For 1 μs max., See *Fig. 7*			4		A
***GATE POWER DISSIPATION:**					
PEAK (For 1 μs max., $I_{GTM} \leq$ 4 A, See *Fig. 7*)	P_{GM}		16		W
AVERAGE	$P_{G(AV)}$		0.5		W
***TEMPERATURE RANGE:▲**					
Storage	T_{stg}		−65 to 150		°C
Operating (Case)	T_C		−65 to 100		°C
***TERMINAL TEMPERATURE (During soldering):**	T_T				
For 10 s max. (terminals and case)			225		°C

* In accordance with JEDEC registration data format (JS-14, RDF 2) filed for the JEDEC (2N-Series) types.
● For either polarity of main terminal 2 voltage (V_{MT2}) with reference to main terminal 1.
■ For either polarity of gate voltage (V_G) with reference to main terminal 1.
▲ For temperature measurement reference point, see Dimensional Outline.

ELECTRICAL CHARACTERISTICS

At Maximum Ratings and at Indicated Case Temperature (T_C) Unless Otherwise Specified

CHARACTERISTIC	SYMBOL	LIMITS For All Types Unless Otherwise Specified Min.	Typ.	Max.	UNITS
Peak Off-State Current:♠ Gate open, T_J = 100° C, V_{DROM} = Max. rated value	I_{DROM}	–	0.1	2*	mA
Maximum On-State Voltage:♠ For i_T = 14 A (peak), T_C = 25° C	V_{TM}	–	1.35	1.65*	V
DC Holding Current:♠ Gate open, Initial principal current = 500 mA (DC), v_D = 12V: T_C = 25° C	I_{HO}	–	15	30	mA
T_C = −65° C		–	75	200*	
For other case temperatures			See *Fig. 6*		
Critical Rate-of-Rise of Commutation Voltage:♠ For v_D = V_{DROM}, $I_{T(RMS)}$ = 10 A, commutating di/dt = 5.4 A/ms, gate unenergized, T_C = 85° C (See *Fig. 14*)	dv/dt	2*	5	–	V/µs
Critical Rate-of-Rise of Off-State Voltage:♠ For v_D = V_{DROM}, exponential voltage rise, gate open, T_C = 100° C: 2N5567, 2N5569, T4121B	dv/dt	30*	150	–	V/µs
2N5568, 2N5570, T4121D		20*	100	–	
T4101M, T4111M, T4121M		10	75	–	
DC Gate-Trigger Current:♠♦ For v_D = 12 V (DC), R_L = 30 Ω, T_C = 25° C — Mode I^+, V_{MT2} positive, V_G positive	I_{GT}	–	10	25	mA
Mode III^-, V_{MT2} negative, V_G negative		–	10	25	
Mode I^-, V_{MT2} positive, V_G negative		–	20	40	
Mode III^+, V_{MT2} negative, V_G positive		–	20	40	
For v_D = 12 V (DC), R_L = 30 Ω, T_C = −65° C — Mode I^+, V_{MT2} positive, V_G positive		–	45	100*	
Mode III^-, V_{MT2} negative, V_G negative		–	45	100*	
Mode I^-, V_{MT2} positive, V_G negative		–	80	150*	
Mode III^+, V_{MT2} negative, V_G positive		–	80	150*	
For other case temperatures			See *Figs. 8 & 9*		
DC Gate-Trigger Voltage:♠♦ For v_D = 12 V(DC), R_L = 30 Ω: T_C = 25° C	V_{GT}		1	2.5	V
T_C = −65° C			2	4*	
For other case temperatures			See *Fig. 10*		
For v_D = V_{DROM}, R_L = 125 Ω, T_C = 100° C		0.2	–	–	
Gate-Controlled Turn-On Time: (Delay Time + Rise Time) For v_D = V_{DROM}, I_{GT} = 160 mA, t_r = 0.1 µs, i_T = 15 A (peak), T_C = 25° C (See *Figs. 11 & 15*)	t_{gt}	–	1.6	2.5	µs
Thermal Resistance: **Junction-to-Case:** Steady-State	$\theta_{J\text{-}C}$	–	–	1*	°C/W
Transient			See *Fig. 12*		
Junction-to-Isolated Hex (Stud, see Dim. Outline): Steady-State	$\theta_{J\text{-}IH}$	–	–	1.1	

* In accordance with JEDEC registration data format (JS-14, RDF 2) filed for the JEDEC (2N-Series) types.

♠ For either polarity of main terminal 2 voltage (V_{MT2}) with reference to main terminal 1.

♦ For either polarity of gate voltage (V_G) with reference to main terminal 1.

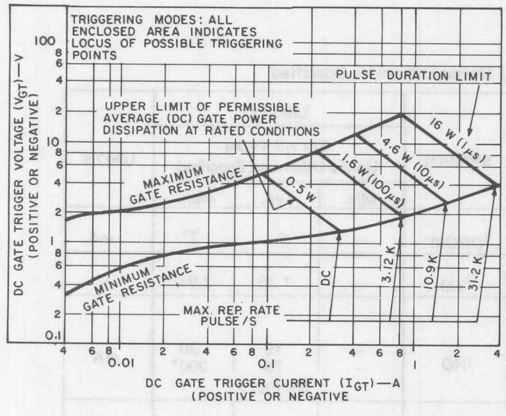


Fig. 7 – Gate trigger characteristics and limiting conditions for determination of permissible gate trigger pulses.

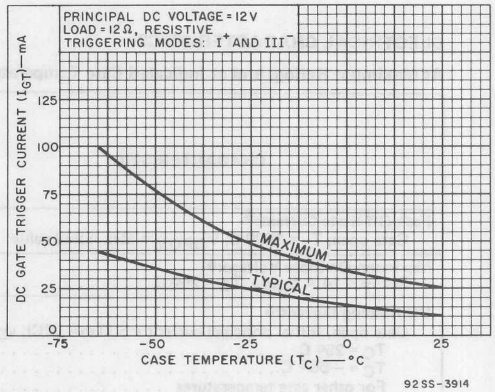


Fig. 8 – DC gate-trigger current vs. case temperature (I^+ & III^- modes).

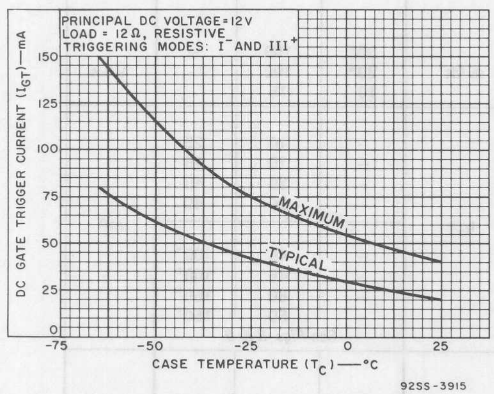


Fig. 9 – DC gate-trigger current vs. case temperature (I^- & III^+ modes).

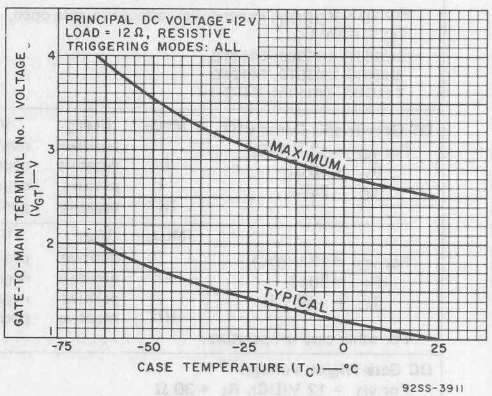


Fig. 10 – DC gate-trigger voltage vs. case temperature.

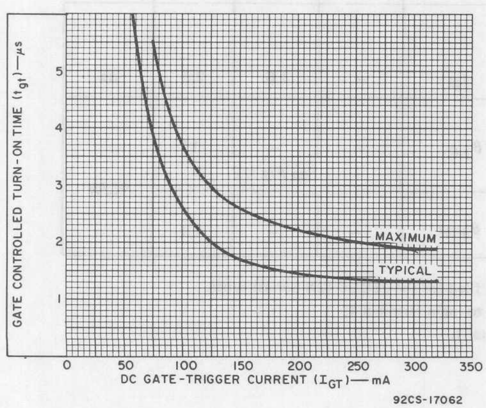


Fig. 11 – Turn-on time vs. gate trigger current.

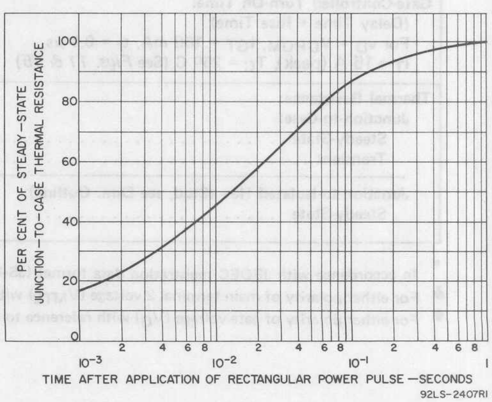


Fig. 12 – Transient junction-to-case thermal resistance vs. time.

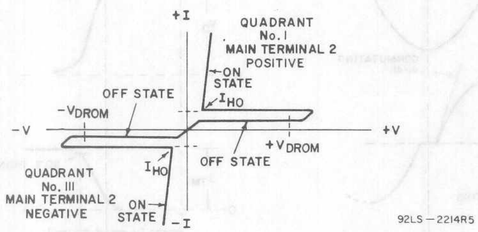


Fig. 1 – Principal voltage-current characteristic.

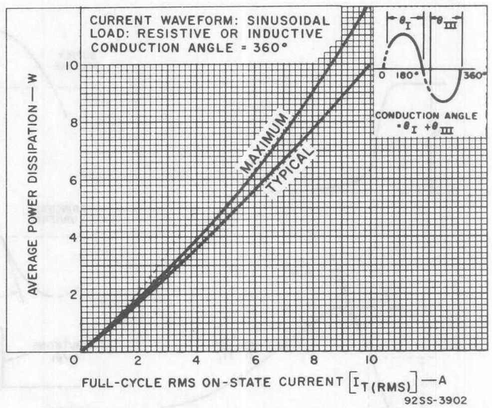


Fig. 2 – Power dissipation vs. on-state current.

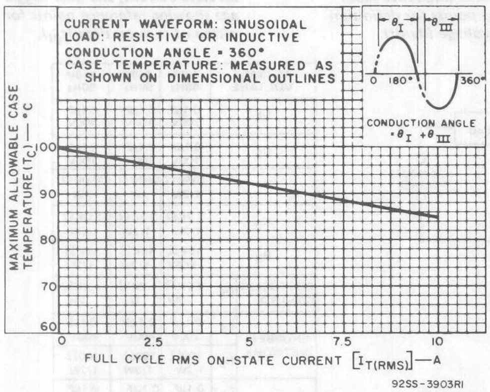


Fig. 3 – Maximum allowable case temperature vs. on-state current.

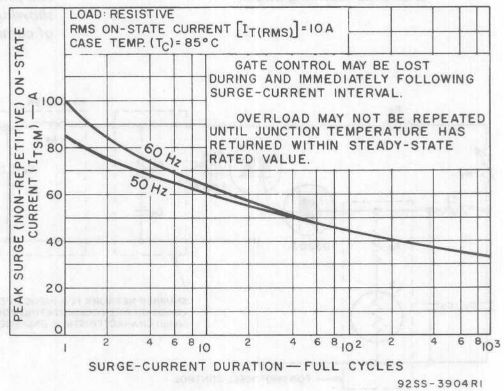


Fig. 4 – Peak surge on-state current vs. surge current duration.

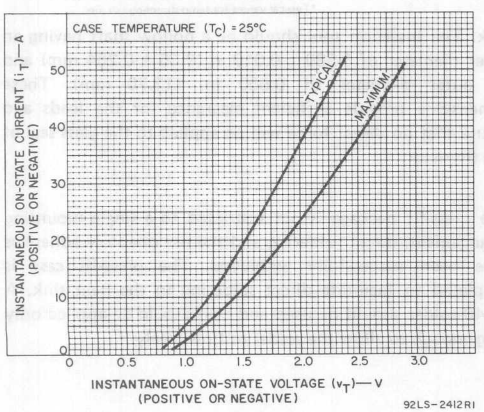


Fig. 5 – On-state current vs. on-state voltage.

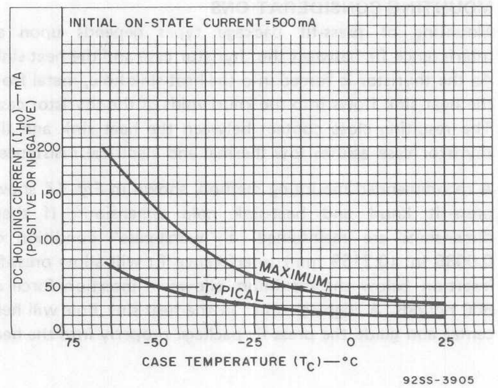


Fig. 6 – DC holding current vs. case temperature.

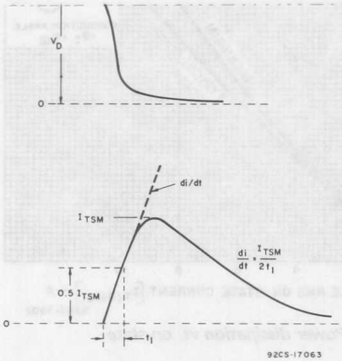


Fig. 13 – Rate-of-change of on-state current with time (defining di/dt).

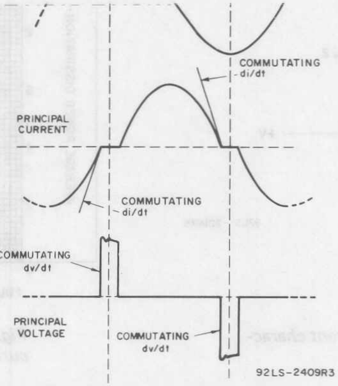


Fig. 14—Relationship between supply voltage and prinicpal current (inductive load) showing reference points for definition of commutating voltage (dv/dt).

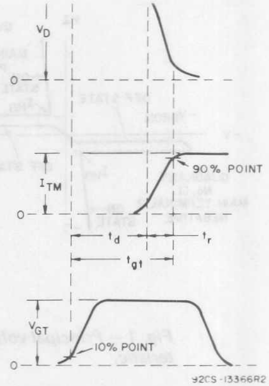


Fig. 15—Relationship between off-state voltage, on-state current, and gate-trigger voltage showing reference points for definition of turn-on time (t_{gt}).

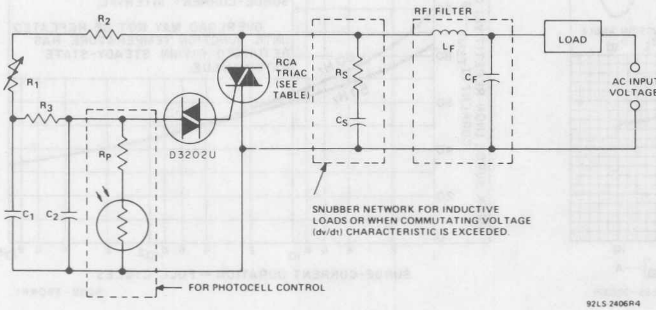


Fig. 16 – Typical phase-control circuit for lamp dimming, heat control, and universal-motor speed control.

AC INPUT VOLTAGE		120V 60Hz	240V 60Hz	240V 50Hz
C_1		0.1μF 200V	0.1μF 400V	0.1μF 400V
C_2		0.1μF 100V	0.1μF 100V	0.1μF 100V
R_1		100KΩ 1/2W	200KΩ 1W	250KΩ 1W
R_2		2.2KΩ 1/2W	3.3KΩ 1/2W	3.3KΩ 1/2W
R_3		15KΩ 1/2W	15KΩ 1/2W	15KΩ 1/2W
PHOTOCELL CONTROL	R_P	1.2KΩ 2W	1.2KΩ 2W	1.2KΩ 2W
SNUBBER NETWORK	C_S	0.1μF 200V	0.1μF 400V	0.1μF 400V
	R_S	100Ω 1/2W	100Ω 1/2W	100Ω 1/2W
RFI FILTER	C_F*	0.1μF 200V	0.1μF 400V	0.1μF 400V
	L_F*	100μH	200μH	200μH
RCA TRIACS		2N5567 2N5569 T4121B	2N5568 2N5570 T4121D	2N5568 2N5570 T4121D

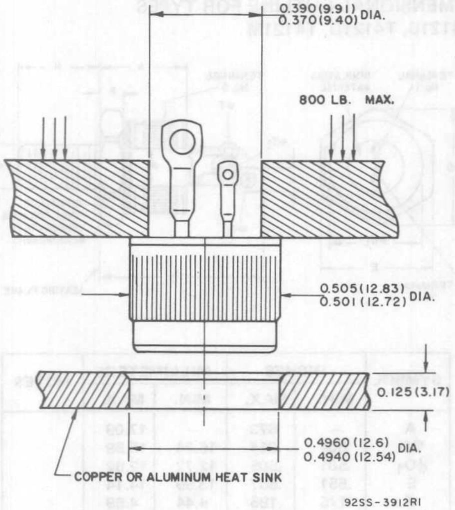
*Typical values for lamp dimming circuits.

MOUNTING CONSIDERATIONS

Mounting of press-fit package types depends upon an interference fit between the thyristor case and the heat sink. As the thyristor is forced into the heat-sink hole, metal from the heat sink flows into the knurl voids of the thyristor case. The resulting close contact between the heat sink and the thyristor case assures low thermal and electrical resistances.

A recommended mounting method, shown in *Fig. 17*, shows press-fit knurl and heat-sink hole dimensions. If these dimensions are maintained, a "worst-case" condition of 0.0085 in. (0.2159 mm) interference fit will allow press-fit insertion below the maximum allowable insertion force of 800 pounds. A slight chamfer in the heat-sink hole will help center and guide the press-fit package properly into the heat sink. The insertion tool should be a hollow shaft having an inner diameter of 0.380 ± 0.010 in (9.65 ± 0.254 mm) and an outer diameter of 0.500 in. (12.70 mm). These dimensions provide sufficient clearance for the leads and assure that no direct force will be applied to the glass seal of the thyristor.

The press-fit package is not restricted to a single mounting arrangement; direct soldering and the use of epoxy adhesives have been successfully employed. The press-fit case is tin-plated to facilitate direct soldering to the heat sink. A 60-40 solder should be used and heat should be applied only long enough to allow the solder to flow freely.



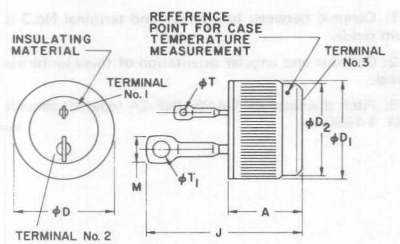
NOTE: Dimensions in parentheses are in millimeters and are derived from the basic inch dimensions as indicated.

Fig. 17 – Suggested mounting method for press-fit package types.

Table I – Case-to-Heat Sink Thermal Resistance for Different Mounting Arrangements.

Package	Type of Mounting Employed	Thermal Resistance-°C/W
Press-Fit	Press-fitted into heat sink. Minimum required thickness of heat sink = 1/8 in. (3.17 mm).	0.5
	Soldered directly to heat sink. (60-40 solder which has a melting point of 188° C should be used. Heating time should be sufficient to cause solder to flow freely).	0.1 to 0.35
Stud & Isolated-Stud	Directly mounted on heat sink with or without the use of heat-sink compound.	0.6
Stud	Mounted on heat sink with a 0.004 to 0.006 in. (0.102 to 0.152 mm) thick mica insulating washer used between unit and heat sink.	
	Without heat sink compound	2.5
	With heat sink compound	1.5

DIMENSIONAL OUTLINE FOR TYPES 2N5567, 2N5568, T4101M



SYMBOL	INCHES		MILLIMETERS		NOTES
	MIN.	MAX.	MIN.	MAX.	
A	–	.380	–	9.65	
ϕD	.501	.510	12.73	12.95	
ϕD1	–	.505	–	12.83	2
ϕD2	.465	.475	11.81	12.07	
J	–	.750	–	19.05	
M	–	.155	–	3.94	1
ϕT	.058	.068	1.47	1.73	
ϕT1	.080	.090	2.03	2.29	

NOTE 1: Contour and angular orientation of these terminals is optional.

NOTE 2: Outer diameter of knurled surface.

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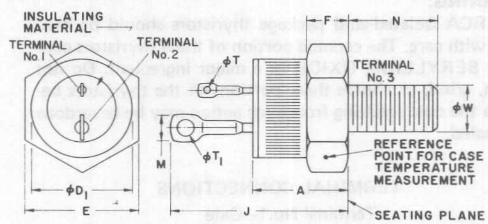
DIMENSIONAL OUTLINE FOR TYPES 2N5569, 2N5570, T4111M



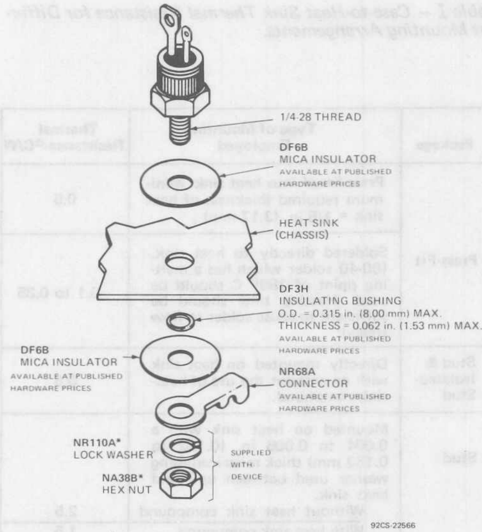
SYMBOL	INCHES		MILLIMETERS		NOTES
	MIN.	MAX.	MIN.	MAX.	
A	.330	.505	8.4	12.8	–
ϕD1	–	.544	–	13.81	–
E	.544	.562	13.82	14.28	–
F	.113	.200	2.87	5.08	3
J	–	.950	–	24.13	–
M	–	.155	–	3.94	1
N	.422	.453	10.72	11.50	–
ϕT	.058	.068	1.47	1.73	–
ϕT1	.080	.090	2.03	2.29	–
ϕW	.2225	.2268	5.652	5.760	2

NOTE 1: Contour and angular orientation of these terminals is optional.

NOTE 2: Pitch diameter of 1/4-28 UNF-2A (coated) threads (ASA B1. 1-1960).

NOTE 3: A chamfer or undercut on one or both ends of hexagonal portion is optional.

92SS-3817



* Only hardware required for isolated-stud package.

In the United Kingdom, Europe, Middle East, and Africa, mounting-hardware policies may differ; check the availability of all items shown with your RCA sales representative or supplier.

Fig. 18 – Suggested mounting arrangement for stud and isolated-stud package types.

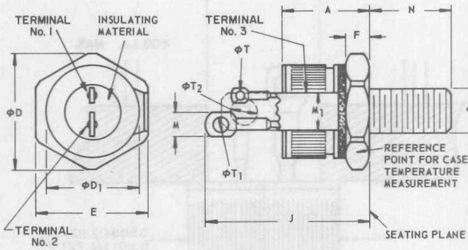
WARNING:

The RCA isolated-stud package thyristors should be handled with care. The ceramic portion of these thyristors contains BERYLLIUM OXIDE as a major ingredient. Do not crush, grind, or abrade these portions of the thyristors because the dust resulting from such action may be hazardous if inhaled.

TERMINAL CONNECTIONS

Terminal No.1–Gate
Terminal No.2–Main Terminal 1
Case, Terminal No.3–Main Terminal 2

DIMENSIONAL OUTLINE FOR TYPES T4121B, T4121D, T4121M



SYMBOL	INCHES		MILLIMETERS		NOTES
	MIN.	MAX.	MIN.	MAX.	
A	–	.673	–	17.09	
ϕD	.604	.614	15.34	15.59	
ϕD_1	.501	.505	12.72	12.82	
E	.551	.557	13.99	14.14	
F	.175	.185	4.44	4.69	
J	–	1.055	–	26.79	
M	–	.155	–	3.94	
M_1	.200	.210	5.08	5.33	
N	.422	.452	10.72	11.48	
ϕT	.058	.068	1.47	1.73	2
ϕT_1	.080	.090	2.03	2.29	2
ϕT_2	.138	.148	3.50	3.75	2
ϕW	.225	.2268	5.652	5.760	3

NOTE 1: Ceramic between hex (stud) and terminal No.3 is beryllium oxide.

NOTE 2: Contour and angular orientation of these terminals is optional.

NOTE 3: Pitch diameter of 1/4-28 UNF-2A (coated) threads (ASA B1. 1-1960).

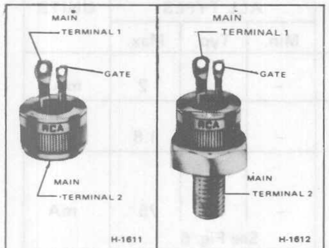
92SS-4413

File No. 443

RCA

Solid State
Division

Thyristors
T4103 T4104 T4105
T4113 T4114 T4115
Series



T4103 Series **T4104 Series** **T4105 Series**	**T4113 Series** **T4114 Series** **T4115 Series**
PRESS-FIT	STUD

400-Hz, 6,10, & 15-A Silicon Triacs

For Control-Systems Application in Airborne and Ground-Support Type Equipment

For 115-V Line Operation – T4103B (40783)●, T4104B (40779)●, T4105B (40775)●, T4113B (40785)●, T4114B (40781)●, T4115B (40777)●

For 208-V Line Operation – T4103D (40784)●, T4104D (40780)●, T4105D (40776)●, T4113D (40786)●, T4114D (40782)●, T4115D (40778)●

●Numbers in parentheses (e.g. 40783) are former RCA type numbers.

Features:

- **RMS On-State Current –**
  $I_{T(RMS)}$ = 6 A: T4105B, T4105D, T4115B, T4115D
  10 A: T4104B, T4104D, T4114B, T4114D,
  15 A: T4103B, T4103D, T4113B, T4113D
- **di/dt Capability = 150 A/μs**
- **Shorted-Emitter Center-Gate Design**
- **Commutating dv/dt Capability Characterized at 400 Hz**

These RCA triacs are gate-controlled full-wave silicon ac switches.

The devices are designed to switch from an off-state to an on-state for either polarity of applied voltage with positive or negative gate triggering voltages.

They are intended for operation up to 400 Hz with resistive or inductive loads and nominal line voltages of 115 and 208 V RMS sine wave and repetitive peak off-state voltages of 200 V and 400 V.

These triacs exhibit commutating voltage (dv/dt) capability at high commutating current (di/dt). They can also be used in 60-Hz applications where high commutating capability is required.

MAXIMUM RATINGS, *Absolute-Maximum Values:*
For Operation with Sinusoidal Supply Voltage at Frequencies up to 400 Hz and with Resistive or Inductive Load.

		T4103B T4113B T4104B T4114B T4105B T4115B	T4103D T4113D T4104D T4114D T4105D T4115D	
REPETITIVE PEAK OFF-STATE VOLTAGE:*	V_{DROM}			
Gate open, T_J = 50 to 100°C		200	400	V
RMS ON-STATE CURRENT (Conduction angle = 360°):	$I_{T(RMS)}$			
Case temperature				
T_C = 90°C (T4105B, T4105D, T4115B, T4115D)		6		A
= 85°C (T4104B, T4104D, T4114B, T4114D)		10		A
= 80°C (T4103B, T4103D, T4113B, T4113D)		15		A
For other conditions		See Fig. 3		
PEAK SURGE (NON-REPETITIVE) ON-STATE CURRENT:	I_{TSM}			
For one cycle of applied principal voltage				
400 Hz (sinusoidal)		200		A
60 Hz (sinusoidal)		100		A
For more than one cycle of applied principal voltage		See Fig. 4		
RATE-OF-CHANGE OF ON-STATE CURRENT:	di/dt			
$V_{DM} = V_{DROM}$, I_{GT} = 160 mA, t_r = 0.1 μs *(See Fig. 13)*		150		A/μs
PEAK GATE-TRIGGER CURRENT:▪	I_{GTM}			
For 1 μs max. *(See Fig. 7)*		4		A
GATE POWER DISSIPATION:				
PEAK (For 1 μs max., $I_{GTM} \leq 4$ A, *See Fig. 7*)	P_{GM}	16		W
AVERAGE	$P_{G(AV)}$	0.2		W
TEMPERATURE RANGE:				
Storage	T_{stg}	-50 to 150		°C
Operating (Case)	T_C	-50 to 100		°C
TERMINAL TEMPERATURE (During soldering):				
For 10 s max. (terminals and case)	T_T	225		°C

* For either polarity of main terminal 2 voltage (V_{MT2}) with reference to main terminal 1.
▪ For either polarity of gate voltage (V_G) with reference to main terminal 1.
▲ For temperature measurement reference point, see Dimensional Outline.

At Maximum Ratings and at Indicated Case Temperature (T_C) Unless Otherwise Specified

CHARACTERISTIC	Mode	V_{MT2}	V_G	SYMBOL	LIMITS ALL TYPES Min.	Typ.	Max.	UNITS
Peak Off-State Current:♠								
Gate open, T_J = 100°C, V_{DROM} = Max. rated value				I_{DROM}	–	0.1	2	mA
Maximum On-State Voltage:♠								
For i_T = 21 A (peak), T_C = 25 °C				V_{TM}	–	1.4	1.8	V
DC Holding Current:♠								
Gate open, Initial principal current = 500 mA (DC), v_D = 12 V, T_C = 25° C				I_{HO}	–	20	75	mA
For other case temperatures						See Fig. 6		
Critical Rate-of-Rise of Commutation Voltage:♠								
For v_D = V_{DROM}, $I_{T(RMS)}$ = rated value, gate unenergized, (See Fig. 14):								
Commutating di/dt = 21.4 A/ms, T_C = 90° C T4105B, T4105D, T4115B, T4115D				dv/dt	5	10	–	V/μs
Commutating di/dt = 36 A/ms, T_C = 85° C T4104B, T4104D, T4114B, T4114D				dv/dt	5	10	–	V/μs
Commutating di/dt = 53.3 A/ms, T_C = 80° C T4103B, T4103D, T4113B, T4113D				dv/dt	5	10	–	V/μs
Critical Rate-of-Rise of Off-State Voltage:♠								
For v_D = V_{DROM}, exponential voltage rise, gate open, T_C = 100° C				dv/dt	30	150	–	V/μs
DC Gate-Trigger Current:♠†								
For v_D = 12 V (DC), R_L = 30 Ω, and T_C = 25 °C	I^+	positive	positive	I_{GT}	–	20	50	mA
	III^-	negative	negative	I_{GT}	–	20	50	mA
	I^-	positive	negative	I_{GT}	–	35	80	mA
	III^+	negative	positive	I_{GT}	–	35	80	mA
For other case temperatures						See Figs. 8 & 9		
DC Gate-Trigger Voltage:♠†								
For v_D = 12 V(DC), R_L = 30Ω, T_C = 25°C				V_{GT}	–	1	2.5	V
For other case temperatures						See Fig. 10		
For v_D = V_{DROM}, R_L = 125Ω, T_C = 100°C				V_{GT}	0.2	–	–	V
Gate-Controlled Turn-On Time: (Delay Time + Rise Time)								
For v_D = V_{DROM}, I_{GT} = 160mA, t_r = 0.1 μs, i_T = 25A (peak), T_C = 25°C, (See Figs. 11 & 15)				t_{gt}	–	1.6	2.5	μs
Thermal Resistance								
Steady-State (Junction-to-Case)				$\theta_{J\text{-}C}$	–	–	1	°C/W
Transient (Junction-to-Case)						See Fig. 12		
Steady-State (Junction-to-Ambient)				$\theta_{J\text{-}A}$	–	–	33	°C/W

♠ For either polarity of main terminal 2 voltage (V_{MT2}) with reference to main terminal 1.

† For either polarity of gate voltage (V_G) with reference to main terminal 1.

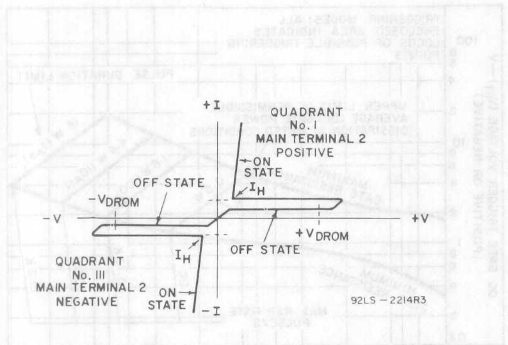


Fig. 1 — Principal voltage-current characteristic.

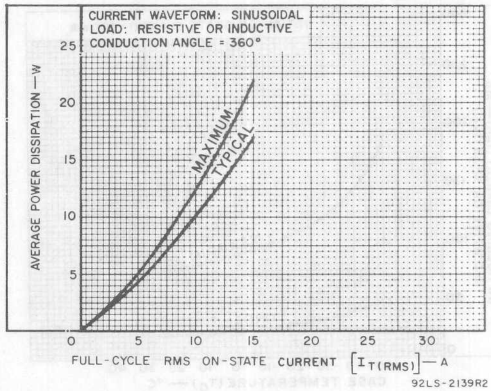


Fig. 2 — Power dissipation vs. on-state current.

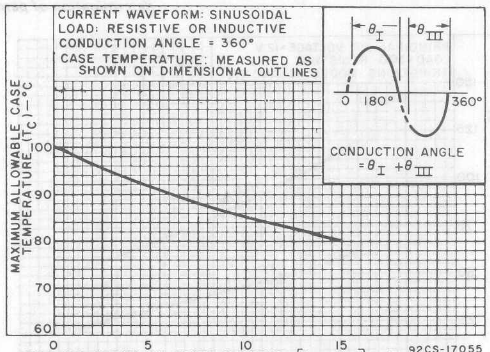


Fig. 3 — Maximum allowable case temperature vs. on-state current.

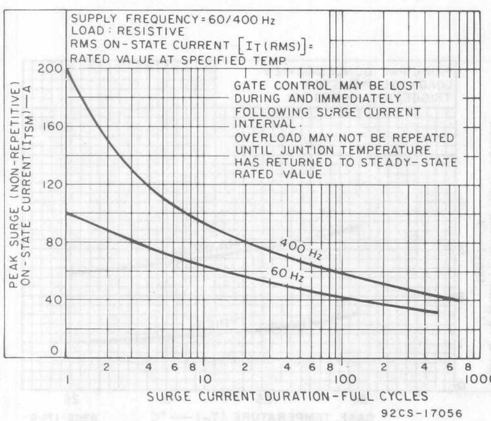


Fig. 4 — Peak surge on-state current vs. surge-current duration.

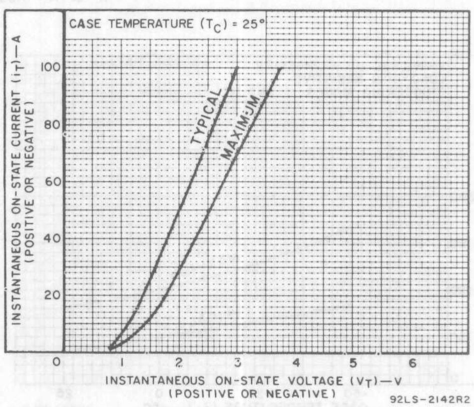


Fig. 5 — On-state current vs. on-state voltage.

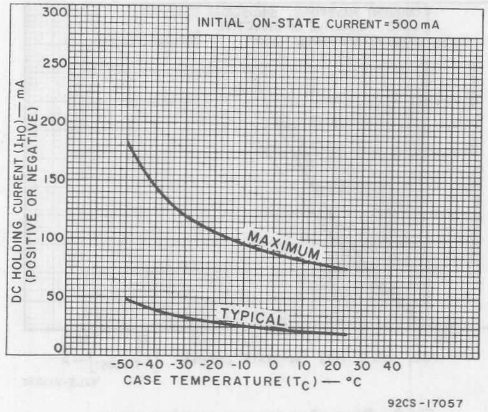
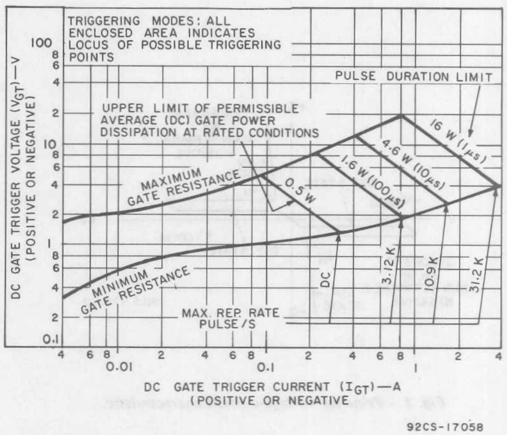


Fig. 6 — DC holding current vs. case temperature.



determination of permissible gate trigger pulses.

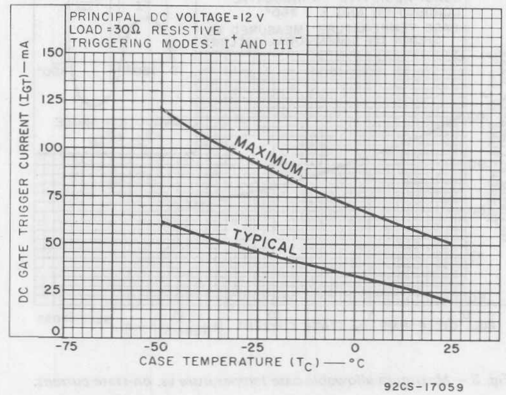


Fig. 8 — DC gate-trigger current vs. case temperature. (I^+ & III^- modes).

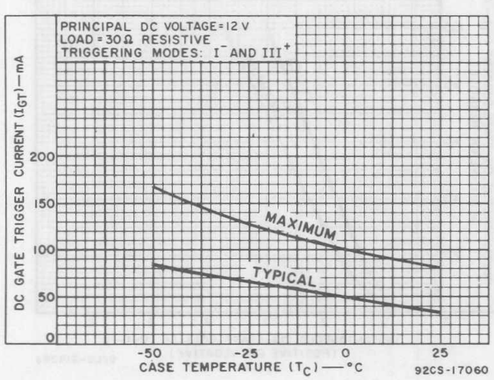


Fig. 9 — DC gate-trigger current vs. case temperature. (I^- & III^+ modes).

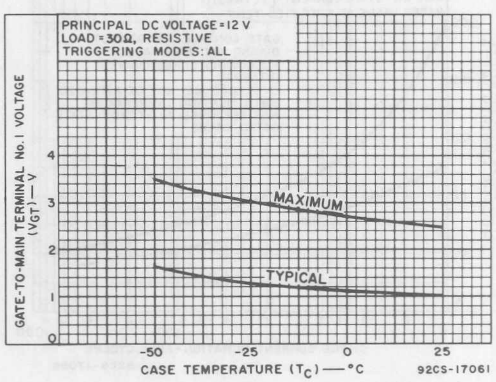


Fig. 10 — DC gate-trigger voltage vs. case temperature.

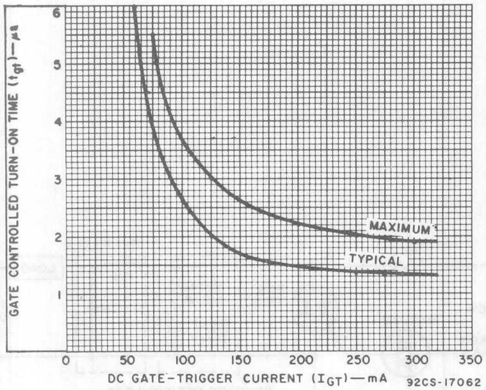


Fig. 11 — Turn-on time vs. gate trigger current.

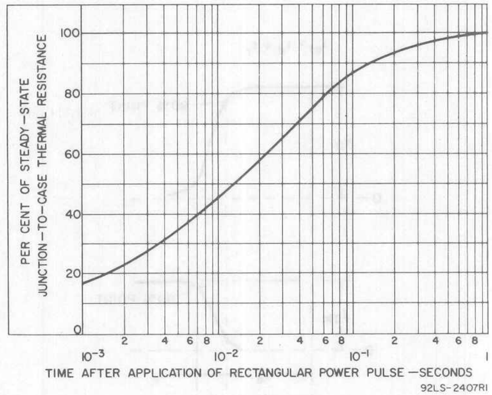


Fig. 12 — Transient thermal resistance vs. time (junction-to-case).

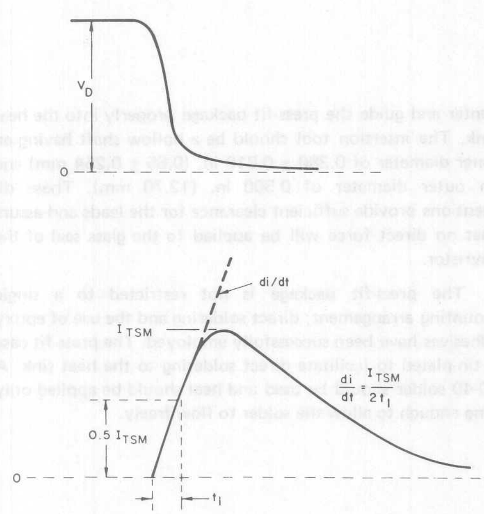


Fig. 13 — Rate of change of on-state current with time (defining di/dt).

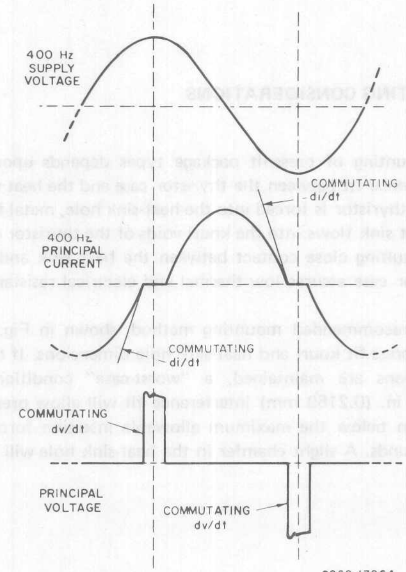


Fig. 14 — Relationship between supply voltage and principal current (inductive load) showing reference points for definition of commutating voltage (dv/dt).

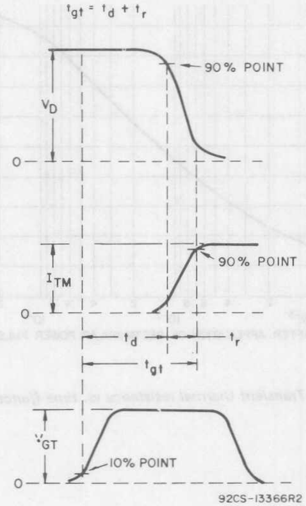


Fig. 15 – Relationship between off-state voltage, on-state current, and gate-trigger voltage showing reference points for definition of turn-on time (t_{gt}).

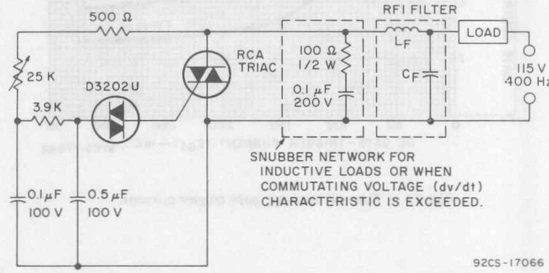


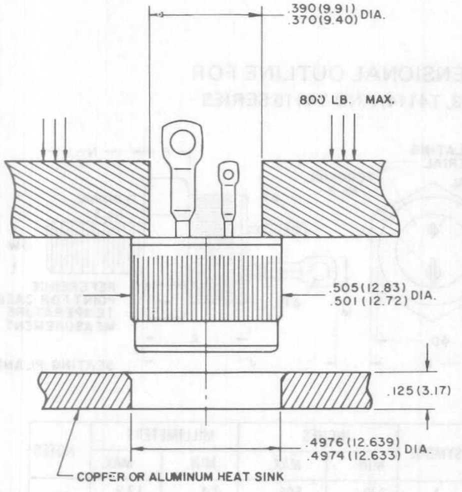
Fig. 16 – Typical phase-control circuit for operation at 400 Hz.

MOUNTING CONSIDERATIONS

Mounting of press-fit package types depends upon an interference fit between the thyristor case and the heat sink. As the thyristor is forced into the heat-sink hole, metal from the heat sink flows into the knurl voids of the thyristor case. The resulting close contact between the heat sink and the thyristor case assures low thermal and electrical resistances.

A recommended mounting method, shown in Fig. 17, shows press-fit knurl and heat-sink hole dimensions. If these dimensions are maintained, a "worst-case" condition of 0.0085 in. (0.2159 mm) interference fit will allow press-fit insertion below the maximum allowable insertion force of 800 pounds. A slight chamfer in the heat-sink hole will help center and guide the press-fit package properly into the heat sink. The insertion tool should be a hollow shaft having an inner diameter of 0.380 ± 0.010 in. (9.65 ± 0.254 mm) and an outer diameter of 0.500 in. (12.70 mm). These dimensions provide sufficient clearance for the leads and assure that no direct force will be applied to the glass seal of the thyristor.

The press-fit package is not restricted to a single mounting arrangement; direct soldering and the use of epoxy adhesives have been successfully employed. The press-fit case is tin-plated to facilitate direct soldering to the heat sink. A 60-40 solder should be used and heat should be applied only long enough to allow the solder to flow freely.

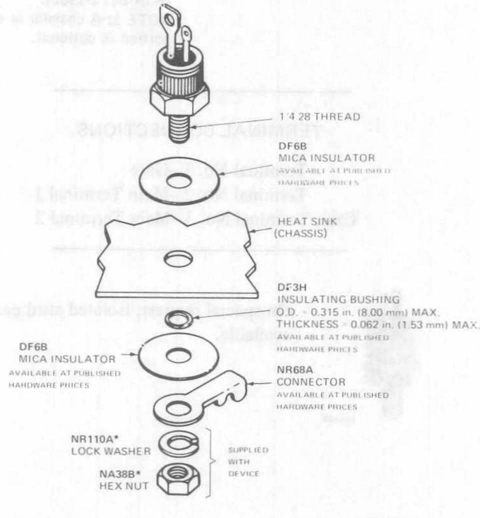


NOTE: Dimensions in parentheses are in millimeters and are derived from the basic inch dimensions as indicated.

Fig. 17 – Suggested mounting method for press-fit package types.

Table 1 - Case-to-Heat Sink Thermal Resistance for Different Mounting Arrangements.

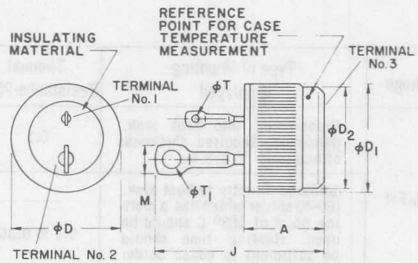
Package	Type of Mounting Employed	Thermal Resistance-^{o}C/W
Press-Fit	Press-fitted into heat sink. (Minimum Required thickness of heat sink = 1/8 in.	0.5
	Soldered directly to heat sink. (60-40 solder which has a melting point of 188^{o} C should be used. Heating time should be sufficient to cause solder to flow freely).	0.1 to 0.35
Stud	Directly mounted on heat sink with or without the use of heat-sink compound.	0.6
	Mounted on heat sink with a 0.004 to 0.006 in. thick mica insulating washer used between unit and heat sink.	
	Without heat sink compound	2.5
	With heat sink compound	1.5



In the United Kingdom, Europe, Middle East, and Africa, mounting-hardware policies may differ; check the availability of all items shown with your RCA sales representative or supplier.

Fig. 18 – Suggested mounting arrangement for stud package types.

DIMENSIONAL OUTLINE FOR T4103, T4104, AND T4105 SERIES

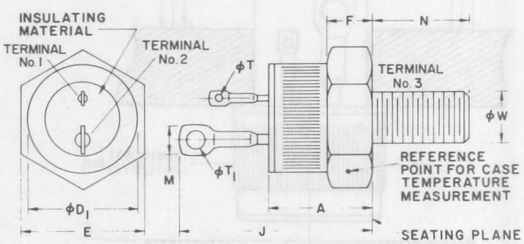


SYMBOL	INCHES MIN.	INCHES MAX.	MILLIMETERS MIN.	MILLIMETERS MAX.	NOTES
A	—	.380		9.65	
φD	.501	.510	12.73	12.95	
φD1	—	.505	—	12.83	2
φD2	.465	.475	11.81	12.07	
J	—	.750	—	19.05	
M	—	.155	—	3.94	1
φT	.058	.068	1.47	1.73	
φT1	.080	.090	2.03	2.29	

NOTE 1: Contour and angular orientation of these terminals is optional.
NOTE 2: Outer diameter of knurled surface.

92SS-3816

DIMENSIONAL OUTLINE FOR T4113, T4114, AND T4115 SERIES



SYMBOL	INCHES MIN.	INCHES MAX.	MILLIMETERS MIN.	MILLIMETERS MAX.	NOTES
A	.330	.505	8.4	12.8	—
φD1	—	.544	—	13.81	—
E	.544	.562	13.82	14.28	—
F	.113	.200	2.87	5.08	3
J	—	.950	—	24.13	—
M	—	.155	—	3.94	1
N	.422	.453	10.72	11.50	—
φT	.058	.068	1.47	1.73	—
φT1	.080	.090	2.03	2.29	—
φW	.2225	.2268	5.652	5.760	2

NOTE 1: Contour and angular orientation of these terminals is optional.
NOTE 2: Pitch diameter of ¼-28 UNF-2A (coated) threads (ASA B1. 1-1960).
NOTE 3: A chamfer or undercut on one or both ends of hexagonal portion is optional.

92SS-3817

TERMINAL CONNECTIONS

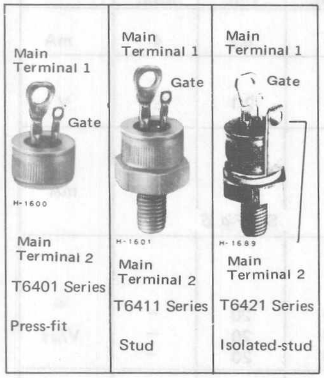
Terminal No. 1–Gate
Terminal No. 2–Main Terminal 1
Case, Terminal No. 3–Main Terminal 2

H-1658

On special request, isolated-stud package triacs are also available.

RCA
Solid State
Division

Thyristors
T6401 T6411 T6421 Series



30-A Silicon Triacs

Press-Fit, Stud, and Isolated-Stud Type Packages

For 120-V Line Operation – T6401B (40660)*, T6411B (40662)*, T6421B (40805)*
For 240-V Line Operation – T6401D (40661)*, T6411D (40663)*, T6421D (40806)*
For High-Voltage Operation – T6401M (40671)*, T6411M (40672)*, T6421M (40807)*

*Numbers in parentheses (e.g. 40660) are former RCA type numbers.

Features:
- **di/dt Capability = 100 A/μs**
- **Shorted-Emitter Center-Gate Design**
- **Low Switching Losses**
- **Low On-State Voltage at High Current Levels**
- **Low Thermal Resistance**

These RCA triacs are gate-controlled full-wave silicon ac switches. They are designed to switch from an off-state to an on-state for either polarity of applied voltage with positive or negative gate triggering voltages.

These triacs are intended for control of ac loads in applications such as heating controls, motor controls, arc-welding equipment, light dimmers, and power switching systems. They can also be used in air-conditioning and photocopying equipment.

MAXIMUM RATINGS, *Absolute-Maximum Values:*
For Operation with Sinusoidal Supply Voltage at Frequencies up to 50/60 Hz and with Resistive or Inductive Load.

		T6401B T6411B T6421B	T6401D T6411D T6421D	T6401M T6411M T6421M	
REPETITIVE PEAK OFF-STATE VOLTAGE:●					
Gate open, T_J = –50 to 100° C	V_{DROM}	200	400	600	V
RMS ON-STATE CURRENT (Conduction angle = 360°):	$I_{T(RMS)}$				
Case temperature					
T_C = 65° C (Press-fit types)			30		A
= 60° C (Stud types)			30		A
= 55° C (Isolated-stud types)			30		A
For other conditions			*See Fig. 3*		
PEAK SURGE (NON-REPETITIVE) ON-STATE CURRENT:	I_{TSM}				
For one cycle of applied principal voltage					
60 Hz (sinusoidal)			300		A
50 Hz (sinusoidal)			265		A
For more than one cycle of applied principal voltage			See *Fig. 4*		
RATE-OF-CHANGE OF ON-STATE CURRENT:	di/dt				
$V_{DM} = V_{DROM}$, I_{GT} = 200 mA, t_r = 0.1 μs (See *Fig. 13*)			100		A/μs
PEAK GATE-TRIGGER CURRENT:■	I_{GTM}				
For 1 μs max., See *Fig. 7*			12		A
GATE POWER DISSIPATION:					
PEAK (For 1 μs max., $I_{GTM} \leq$ 4 A, See *Fig. 7*)	P_{GM}		40		W
AVERAGE	$P_{G(AV)}$		0.75		W
TEMPERATURE RANGE:▲					
Storage	T_{stg}		–65 to 150		°C
Operating (Case)	T_C		–65 to 100		°C
TERMINAL TEMPERATURE (During soldering):	T_T				
For 10 s max. (terminals and case)			225		°C

● For either polarity of main terminal 2 voltage (V_{MT2}) with reference to main terminal 1.
■ For either polarity of gate voltage (V_G) with reference to main terminal 1.
▲ For temperature measurement reference point, see Dimensional Outline.

CHARACTERISTIC	SYMBOL	LIMITS For All Types Unless Otherwise Specified Min.	 Typ.	 Max.	UNITS
Peak Off-State Current:♠ Gate open, T_J = 100° C, V_{DROM} = Max. rated value	I_{DROM}	–	0.2	4	mA
Maximum On-State Voltage:♠ For i_T = 100 A (peak), T_C = 25° C	V_{TM}	–	2.1	2.5	V
DC Holding Current:♠ Gate open, Initial principal current = 150 mA (DC), v_D = 12V: T_C = 25° C For other case temperatures	I_{HO}	– 	25 See *Fig. 6*	60 	mA
Critical Rate-of-Rise of Commutation Voltage:♠ For v_D = V_{DROM}, $I_{T(RMS)}$ = 30 A, commutating di/dt = 16 A/ms, gate unenergized, (See *Fig. 14*): T_C = 65° C (Press-fit types) = 60° C (Stud types) = 55° C (Isolated-stud types)	dv/dt	 3 3 3	 20 20 20	 – – –	V/μs
Critical Rate-of-Rise of Off-State Voltage:♠ For v_D = V_{DROM}, exponential voltage rise, gate open, T_C = 100° C: T6401B, T6411B, T6421B T6401D, T6411D, T6421D T6401M, T6411M, T6421M	dv/dt	 40 25 20	 200 150 100	 – – –	V/μs
DC Gate-Trigger Current:♠♦ Mode / V_{MT2} / V_G For v_D = 12 V (DC), I⁺ positive positive R_L = 30 Ω, III⁻ negative negative T_C = 25° C I⁻ positive negative III⁺ negative positive For other case temperatures	I_{GT}	 – – – – 	 15 20 30 40 See *Figs. 8 & 9*	 50 50 80 80 	mA
DC Gate-Trigger Voltage:♠♦ For v_D = 12 V(DC), R_L = 30 Ω, T_C = 25° C For other case temperatures For v_D = V_{DROM}, R_L = 125 Ω, T_C = 100° C	V_{GT}	 – 0.2	 1.35 See *Fig. 10* 	 2.5 	V
Gate-Controlled Turn-On Time: (Delay Time + Rise Time) For v_D = V_{DROM}, I_{GT} = 200 mA, t_r = 0.1 μs, i_T = 45 A (peak), T_C = 25° C (See *Figs. 11 & 15*)	t_{gt}	–	1.7	3	μs
Thermal Resistance, Junction-to-Case: Steady-State Press-fit types Stud Transient (Press-fit & stud types)	$\theta_{J\text{-}C}$	 – – 	 – – See *Fig. 12*	 0.8 0.9 	°C/W
Thermal Resistance, Junction-to-Hex (Stud, See Dim. Outline): Steady-State (Isolated-stud types)	$\theta_{J\text{-}IH}$	–	–	1	

♠ For either polarity of main terminal 2 voltage (V_{MT2}) with reference to main terminal 1.
♦ For either polarity of gate voltage (V_G) with reference to main terminal 1.

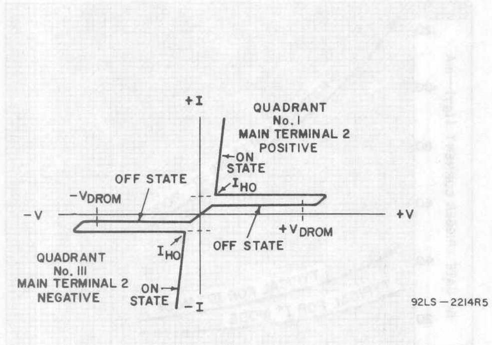


Fig. 1 – Principal voltage-current characteristic.

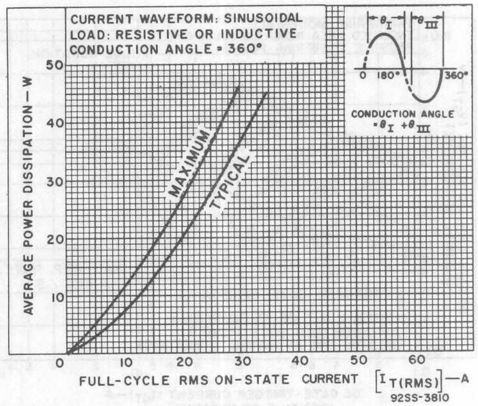


Fig. 2 – Power dissipation vs. on-state current.

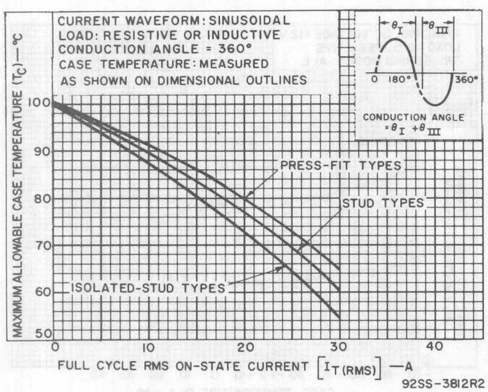


Fig. 3 – Maximum allowable case temperature vs. on-state current.

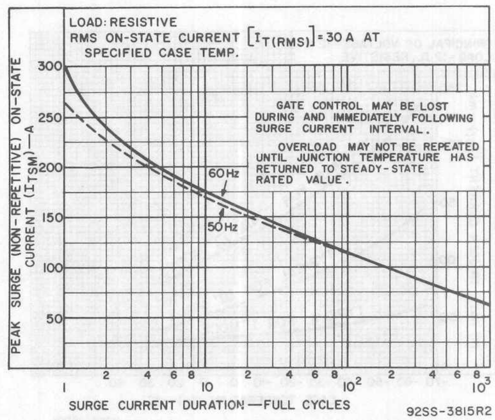


Fig. 4 – Peak surge on-state current vs. surge current duration.

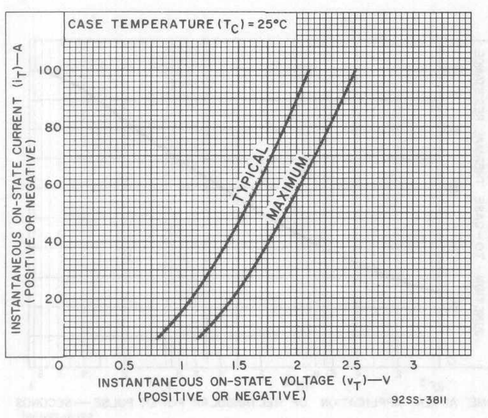


Fig. 5 – On-state current vs. on-state voltage.

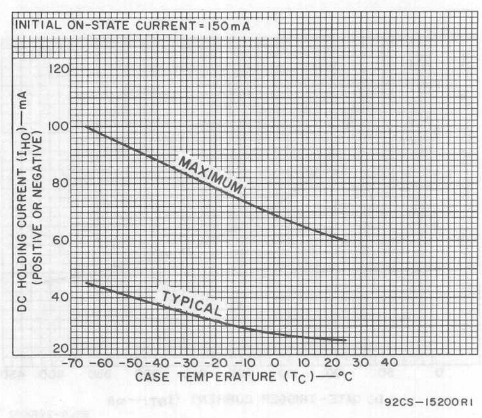


Fig. 6 – DC holding current vs. case temperature.

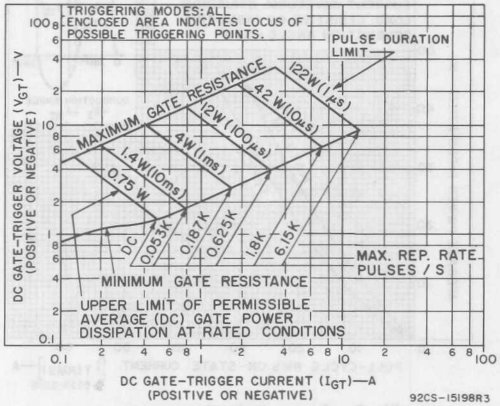


Fig. 7 – Gate trigger characteristics and limiting conditions for determination of permissible gate trigger pulses.

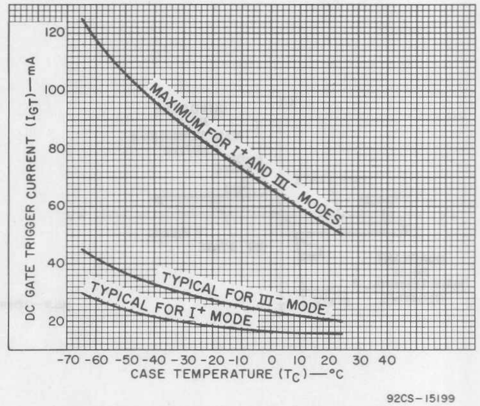


Fig. 8 – DC gate-trigger current vs. case temperature (1^+ & III^- modes).

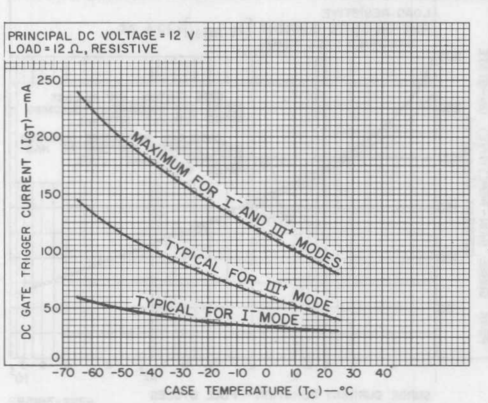


Fig. 9 – DC gate-trigger current vs. case temperature (1^- & III^+ modes).

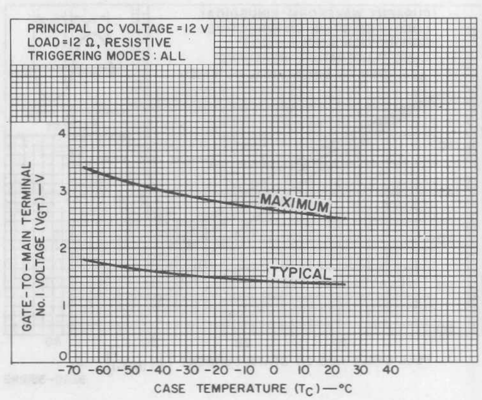


Fig. 10 – DC gate-trigger voltage vs. case temperature.

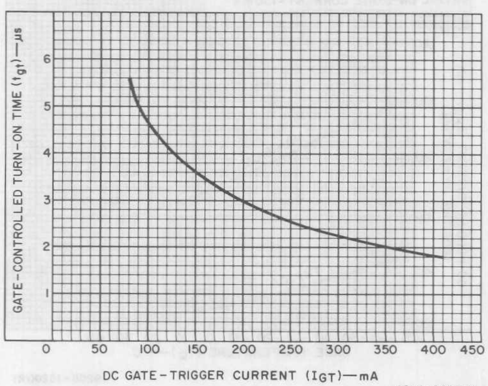


Fig. 11 – Turn-on time vs. gate trigger current.

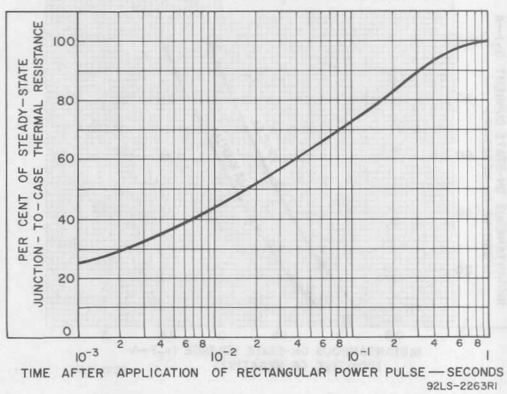


Fig. 12 – Transient junction-to-case thermal resistance vs. time.

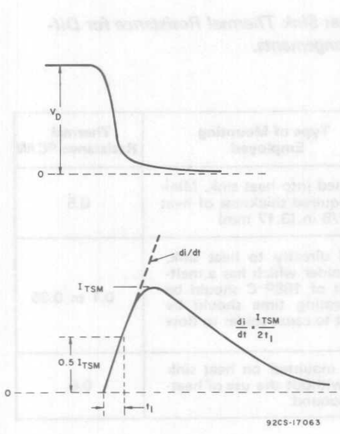


Fig. 13 – Rate of change of on-state current with time (defining di/dt).

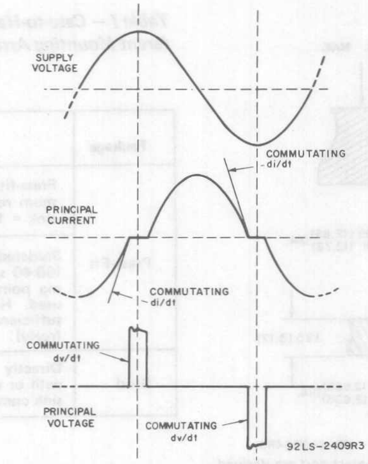


Fig. 14 – Relationship between supply voltage and principle current (inductive load) showing reference points for definition of commutating voltage (dv/dt).

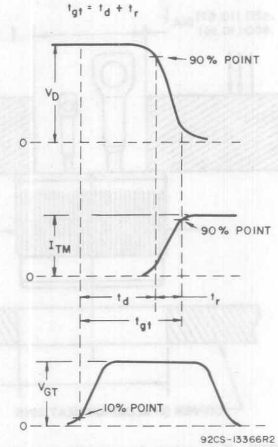


Fig. 15 – Relationship between off-state voltage, on-state current, and gate-trigger voltage showing reference points for definition of turn-on time (t_{gt}).

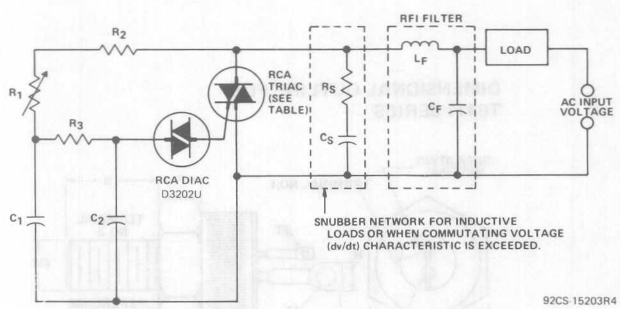


Fig. 16 – Typical phase-control circuit for lamp dimming, heat control, and universal-motor speed control.

AC INPUT VOLTAGE		120V 60Hz	240V 60Hz	240V 50Hz
C_1		0.1µF 200V	0.1µF 400V	0.1µF 400V
C_2		0.1µF 100V	0.1µF 100V	0.1µF 100V
R_1		100KΩ 1/2W	200KΩ 1W	250KΩ 1W
R_2		2.2KΩ 1/2W	3.3KΩ 1/2W	3.3KΩ 1/2W
R_3		15KΩ 1/2W	15KΩ 1/2W	15KΩ 1/2W
SNUBBER NETWORK	C_S	0.1µF 200V	0.1µF 400V	0.1µF 400V
	R_S	100Ω 1/2W	100Ω 1/2W	100Ω 1/2W
RFI FILTER	C_F*	0.1µF 200V	0.1µF 400V	0.1µF 400V
	L_F*	100µH	200µH	200µH
RCA TRIACS		T6401B T6411B T6421B	T6401D T6411D T6421D	T6401D T6411D T6421D

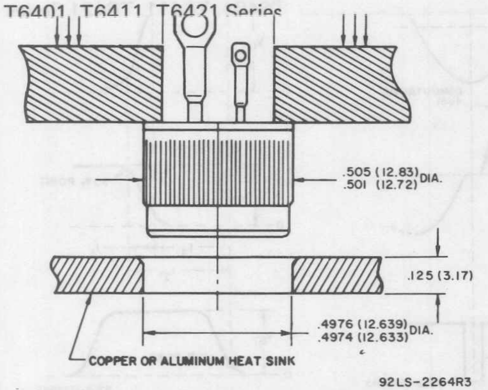
*Typical values for lamp dimming circuits.

MOUNTING CONSIDERATIONS

Mounting of press-fit package types depends upon an interference fit between the thyristor case and the heat sink. As the thyristor is forced into the heat-sink hole, metal from the heat sink flows into the knurl voids of the thyristor case. The resulting close contact between the heat sink and the thyristor case assures low thermal and electrical resistances.

A recommended mounting method, shown in *Fig. 17*, shows press-fit knurl and heat-sink hole dimensions. If these dimensions are maintained, a "worst-case" condition of 0.0085 in. (0.2159 mm) interference fit will allow press-fit insertion below the maximum allowable insertion force of 800 pounds. A slight chamfer in the heat-sink hole will help center and guide the press-fit package properly into the heat sink. The insertion tool should be a hollow shaft having an inner diameter of 0.380 ± 0.010 in. (9.65 ± 0.254 mm) and an outer diameter of 0.500 in. (12.70 mm). These dimensions provide sufficient clearance for the leads and assure that no direct force will be applied to the glass seal of the thyristor.

The press-fit package is not restricted to a single mounting arrangement; direct soldering and the use of epoxy adhesives have been successfully employed. The press-fit case is tin-plated to facilitate direct soldering to the heat sink. A 60-40 solder should be used and heat should be applied only long enough to allow the solder to flow freely.

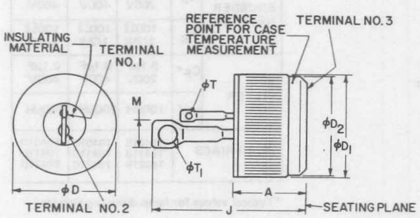


NOTE: Dimensions in parentheses are in millimeters and are derived from the basic inch dimensions as indicated.

Fig. 17 – Suggested mounting method for press-fit package types.

Package	Type of Mounting Employed	Thermal Resistance-°C/W
Press-Fit	Press-fitted into heat sink. Minimum required thickness of heat sink = 1/8 in. (3.17 mm)	0.5
	Soldered directly to heat sink. (60-40 solder which has a melting point of 188° C should be used. Heating time should be sufficient to cause solder to flow freely).	0.1 to 0.35
Stud	Directly mounted on heat sink with or without the use of heat-sink compound.	0.6

DIMENSIONAL OUTLINE FOR T6401 SERIES

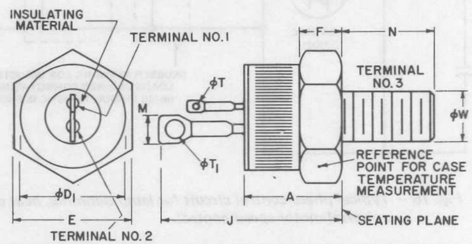


SYMBOL	INCHES MIN.	INCHES MAX.	MILLIMETERS MIN.	MILLIMETERS MAX.	NOTES
A	–	.380	–	9.65	
φD	.501	.510	12.73	12.95	
φD_1	–	.505	–	12.83	2
φD_2	.465	.475	11.81	12.07	
J	–	.750	–	19.05	
M	–	.155	–	3.94	1
φT	.058	.068	1.47	1.73	
φT_1	.080	.090	2.03	2.29	

NOTE 1: Contour and angular orientation of these terminals is optional.

NOTE 2: Outer diameter of knurled surface. 92CS-15207R2

DIMENSIONAL OUTLINE FOR T6411 SERIES



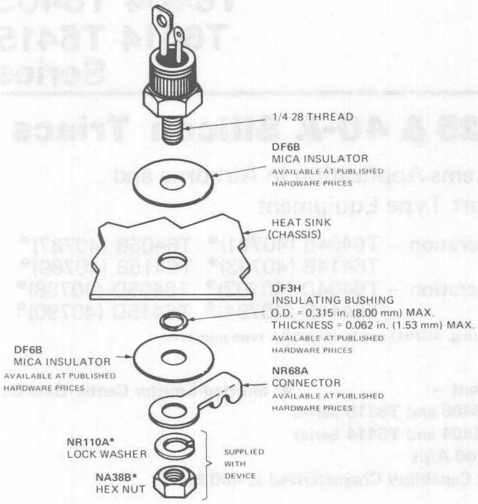
SYMBOL	INCHES MIN.	INCHES MAX.	MILLIMETERS MIN.	MILLIMETERS MAX.	NOTES
A	.330	.505	8.4	12.8	–
φD_1	–	.544	–	13.81	–
E	.544	.562	13.82	14.28	–
F	.113	.200	2.87	5.08	3
J	–	.950	–	24.13	–
M	–	.155	–	3.94	1
N	.422	.453	10.72	11.50	–
φT	.058	.068	1.47	1.73	–
φT_1	.080	.090	2.03	2.29	–
φW	.2225	.2268	5.652	5.760	2

NOTE 1: Contour and angular orientation of these terminals is optional.

NOTE 2: Pitch diameter of 1/4-28 UNF-2A (coated) threads (ASA B1. 1-1960).

NOTE 3: A chamfer or undercut on one or both ends of hexagonal portion is optional.

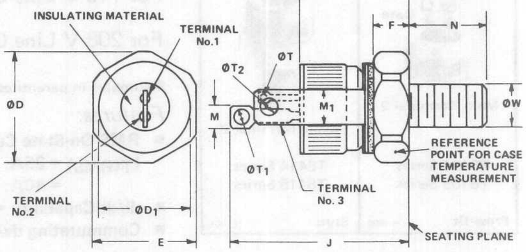
92CS-15208R2



In the United Kingdom, Europe, Middle East, and Africa, mounting-hardware policies may differ; check the availability of all items shown with your RCA sales representative or supplier.

Fig. 18 – Suggested mounting arrangement for stud and isolated-stud package types.

DIMENSIONAL OUTLINE FOR T6421 SERIES



SYMBOL	INCHES		MILLIMETERS		NOTES
	MIN.	MAX.	MIN.	MAX.	
A	–	.673	–	17.09	
ϕD	.604	.614	15.34	15.59	
ϕD_1	.501	.505	12.72	12.82	
E	.551	.557	13.99	14.14	
F	.175	.185	4.44	4.69	
J	–	1.298	–	32.96	
M	.210	.230	5.33	5.84	
M_1	.200	.210	5.08	5.33	
N	.422	.452	10.72	11.48	
ϕT	.058	.068	1.47	1.73	2
ϕT_1	.125	.165	3.18	4.19	2
ϕT_2	.138	.148	3.50	3.75	2
ϕW	.2225	.2268	5.652	5.760	3

NOTE 1: Ceramic between hex (stud) and terminal No.3 is beryllium oxide.

NOTE 2: Contour and angular orientation of these terminals is optional.

NOTE 3: Pitch diameter of 1/4-28 UNF-2A (coated) threads (ASA B1. 1-1960).

92LS-3653

WARNING:
The RCA isolated-stud package thyristors should be handled with care. The ceramic portion of these thyristors contains BERYLLIUM OXIDE as a major ingredient. Do not crush, grind, or abrade these portions of the thyristors because the dust resulting from such action may be hazardous if inhaled.

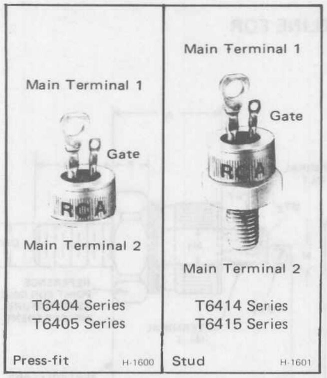
TERMINAL CONNECTIONS

Terminal No.1–Gate
Terminal No.2–Main Terminal 1
Case, Terminal No.3–Main Terminal 2

RCA
Solid State Division

Thyristors

T6404 T6405 T6414 T6415 Series



400-Hz, 25 & 40-A Silicon Triacs

For Control-Systems Application in Airborne and Ground-Support Type Equipment

For 115-V Line Operation – T6404B (40791)• T6405B (40787)• T6414B (40793)• T6415B (40789)•
For 208-V Line Operation – T6404D (40792)• T6405D (40788)• T6414D (40794)• T6415D (40790)•

•Numbers in parentheses (e.g. 40791) are former RCA type numbers.

Features:

- **RMS On-State Current –** **$I_{T(RMS)}$ = 25A: T6405 and T6415 Series** **= 40A: T6404 and T6414 Series**
- **di/dt Capability = 100 A/μs**
- **Commutating dv/dt Capability Characterized at 400 Hz**
- **Shorted-Emitter Center-Gate Design**

These RCA triacs are gate-controlled full-wave silicon ac switches. They are designed to switch from an off-state to an on-state for either polarity of applied voltage with positive or negative gate triggering voltages.

They are intended for operation at 400 Hz with resistive or inductive loads and nominal line voltages of 115 and 208 V RMS sine wave and repetitive peak off-state voltages of 200 V and 400 V.

These triacs exhibit commutating voltage (dv/dt) capability at high commutating current (di/dt). They can also be used in 60-Hz applications where high commutating capability is required.

MAXIMUM RATINGS, *Absolute-Maximum Values:*
For Operation with Sinusoidal Supply Voltage at 400 Hz and with Resistive or Inductive Load.

		T6404B T6405B T6414B T6415B	T6404D T6405D T6414D T6415D	
REPETITIVE PEAK OFF-STATE VOLTAGE:*	V_{DROM}			
Gate open, T_J = –50 to 110° C		200	400	V
RMS ON-STATE CURRENT (Conduction Angle = 360°):	$I_{T(RMS)}$			
Case temperature				
T_C = 85° C (T6405 Series)		25		A
80° C (T6415 Series)		25		A
70° C (T6404 Series)		40		A
65° C (T6414 Series)		40		A
For other conditions		See Fig.3		
PEAK SURGE (NON-REPETITIVE) ON-STATE CURRENT:	I_{TSM}			
For one cycle of applied principal voltage				
400 Hz (sinusoidal)		600		A
60 Hz (sinusoidal)		300		A
For more than one cycle of applied principal voltage		See Fig.4		
RATE-OF-CHANGE OF ON-STATE CURRENT:	di/dt			
$V_{DM} = V_{DROM}$, I_{GT} = 200 mA, t_r = 0.1 μs *(See Fig. 15)*		100		A/μs
FUSING CURRENT (for Triac Protection):	I^2t			
T_J = –50 to 110° C, t = 1.25 to 10 ms		350		A^2s
PEAK GATE-TRIGGER CURRENT:■	I_{GTM}			
For 1 μs max. *(See Fig. 7)*		12		A
GATE POWER DISSIPATION:				
Peak (For 10 μs max., $I_{GTM} \leq$ 4 A (peak), *(See Fig. 7)*	P_{GM}	42		W
Average	$P_{G(AV)}$	0.75		W
TEMPERATURE RANGE:▲				
Storage	T_{stg}	–50 to 150		°C
Operating (Case)	T_C	–50 to 110		°C
TERMINAL TEMPERATURE (During soldering):	T_T			
For 10 s max. (terminals and case)		225		°C

* For either polarity of main terminal 2 voltage (V_{MT2}) with reference to main terminal 1.
■ For either polarity of gate voltage (V_G) with reference to main terminal 1.
▲ For temperature measurement reference point, see Dimensional Outline.

ELECTRICAL CHARACTERISTICS
At Maximum Ratings and at Indicated Case Temperature (T_C) Unless Otherwise Specified

CHARACTERISTIC	SYMBOL	LIMITS For All Types Unless Otherwise Specified			UNITS
		Min.	Typ.	Max.	
Peak Off-State Current:♠ Gate open, T_J = 110° C, V_{DROM} = Max. rated value	I_{DROM}	–	0.2	4	mA
Maximum On-State Voltage:♠ For i_T = 100 A (peak), T_C = 25° C:	V_{TM}				V
T6405 & T6415 Series		–	1.7	2.5	
T6404 & T6414 Series		–	1.7	2	
DC Holding Current:♠ Gate open, Initial principal current = 500 mA (DC), v_D = 12 V, T_C = 25° C	I_{HO}	–	30	90	mA
For other case temperatures			See Fig.6		
Critical Rate-of-Rise of Commutation Voltage:♠ For v_D = V_{DROM}, $I_{T(RMS)}$ = rated value, gate unenergized, (See Figs.13 & 14): Commutating di/dt = 88 A/ms	dv/dt				V/μs
T_C = 85° C (T6405 Series)		2	–	–	
= 80° C (T6415 Series)		2	–	–	
Commutating di/dt = 141 A/ms T_C = 70° C (T6404 Series)		2	–	–	
= 65° C (T6414 Series)		2	–	–	
Critical Rate-of-Rise of Off-State Voltage:♠ For v_D = V_{DROM}, exponential voltage rise, gate open, T_C = 110° C:	dv/dt				V/μs
T6405 & T6415 Series		30	150	–	
T6404 & T6414 Series		50	200	–	
DC Gate-Trigger Current:♠† For v_D = 12 V (DC), R_L = 30 Ω, T_C = 25° C — Mode I+, V_{MT2} positive, V_G positive	I_{GT}	–	20	80	mA
Mode III−, V_{MT2} negative, V_G negative		–	50	80	
Mode I−, V_{MT2} positive, V_G negative		–	80	120	
Mode III+, V_{MT2} negative, V_G positive		–	80	120	
For other case temperatures			See Figs.8 & 9		
DC Gate-Trigger Voltage:♠† For v_D = 12 V(DC), R_L = 30 Ω, T_C = 25° C	V_{GT}	–	2	3	V
For other case temperatures			See Fig. 10		
For v_D = V_{DROM}, R_L = 125 Ω, T_C = 110° C		0.2	–	–	
Gate-Controlled Turn-On Time: (Delay Time + Rise Time) For v_D = V_{DROM}, I_{GT} = 150 mA, t_r = 0.1 μs, i_T = 60 A (peak), T_C = 25° C (See Figs. 11 & 12)	t_{gt}	–	1.6	2.5	μs
Thermal Resistance, Junction-to-Case: Steady-State Press-fit types	$\theta_{J\text{-}C}$	–	–	0.8	°C/W
Stud		–	–	0.9	
Transient (Press-fit & stud types)			See Fig. 16		

♠ For either polarity of main terminal 2 voltage (V_{MT2}) with reference to main terminal 1.

† For either polarity of gate voltage (V_G) with reference to main terminal 1.

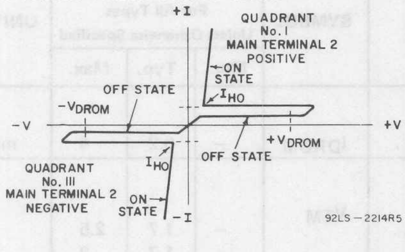


Fig. 1 — Principal voltage-current characteristic.

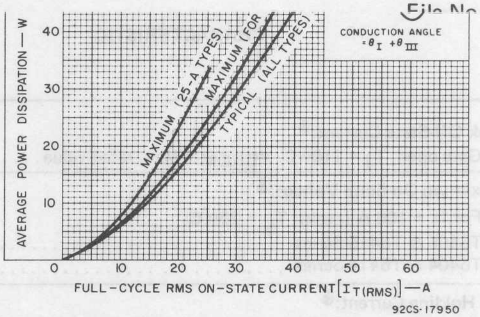


Fig. 2 — Power dissipation vs. on-state current.

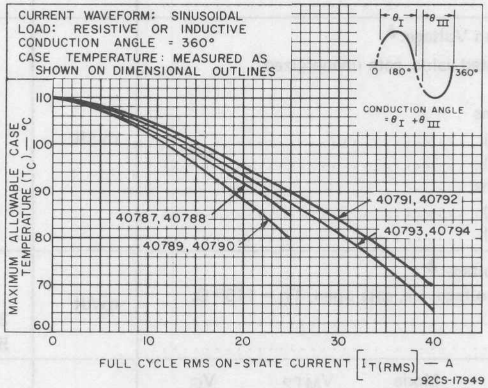


Fig. 3 — Maximum allowable case temperature vs. on-state current.

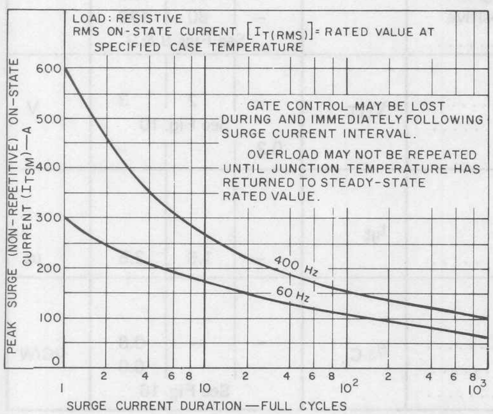


Fig. 4 — Peak surge on-state current vs. surge current duration.

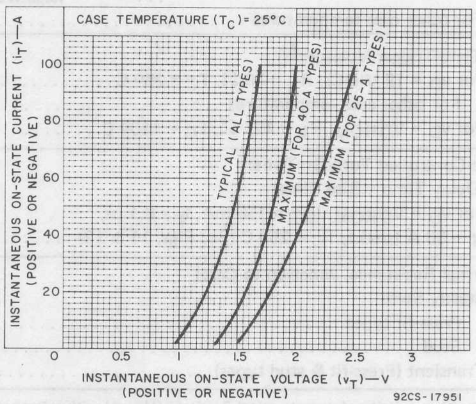


Fig. 5 — On-state current vs. on-state voltage.

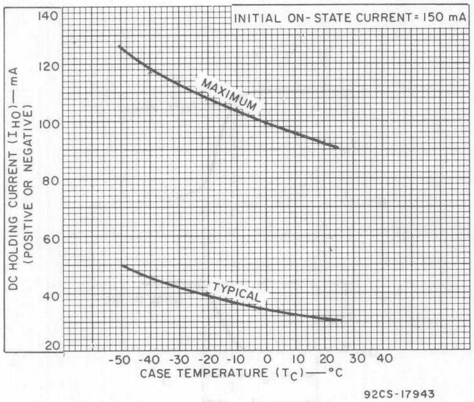


Fig. 6 — DC holding current vs. case temperature.

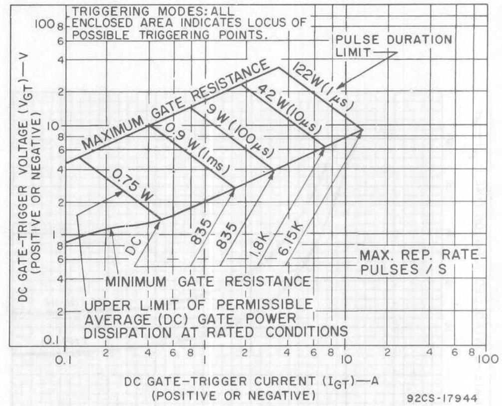


Fig. 7 — Gate-trigger characteristics and limiting conditions for determination of permissible gate-trigger pulses.

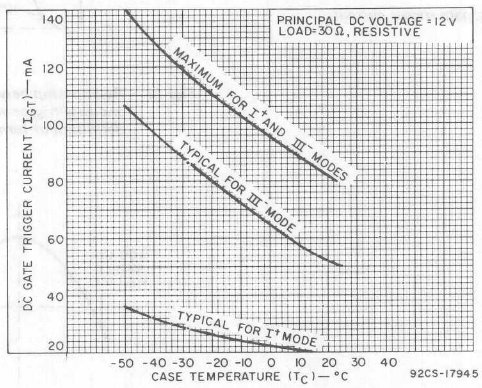


Fig. 8 — DC gate-trigger current vs. case temperature (I^+ & III^- modes).

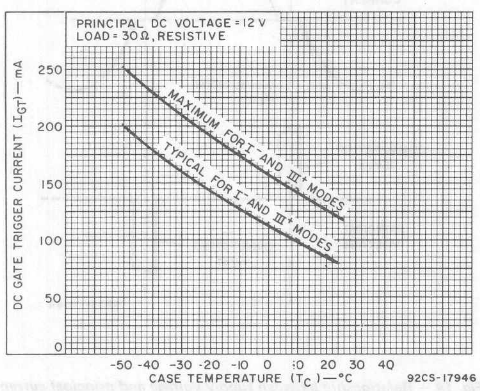


Fig. 9 — DC gate-trigger current vs. case temperature (I^- & III^+ modes).

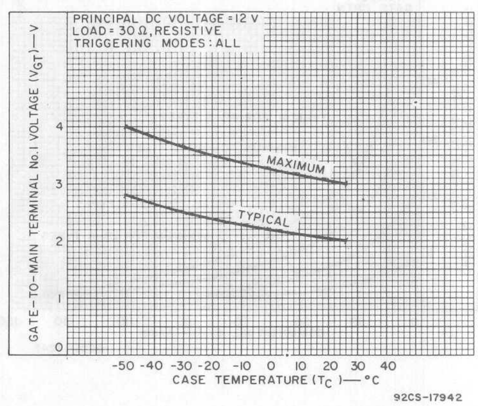


Fig. 10 — DC gate-trigger voltage vs. case temperature.

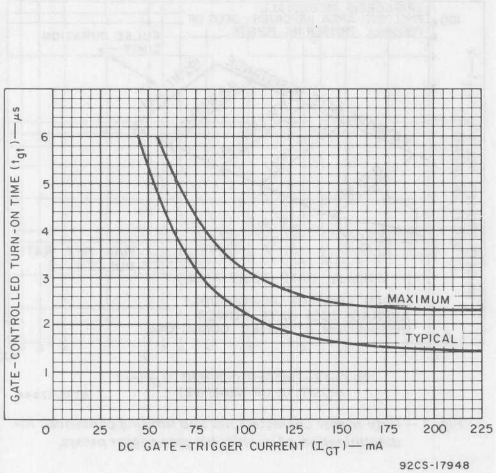


Fig. 11 — Turn-on time vs. gate trigger current.

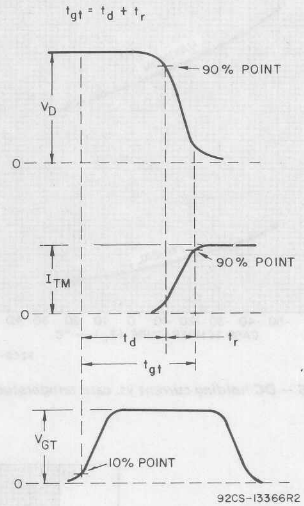


Fig. 12 — Relationship between off-state voltage, on-state current, and gate-trigger voltage showing reference points for definition of turn-on time (t_{gt}).

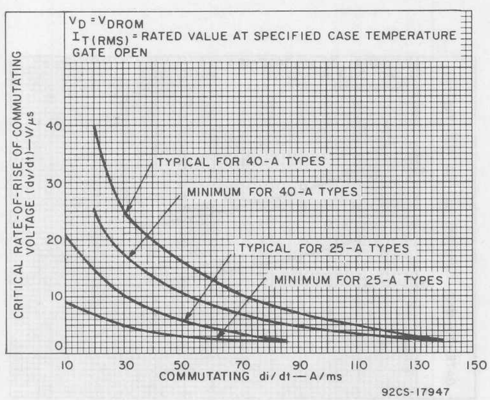


Fig. 13 — Commutating voltage vs. commutating current.

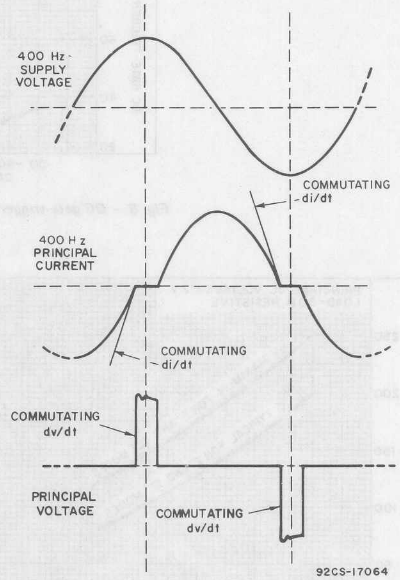


Fig. 14 — Relationship between supply voltage and principal current (inductive load) showing reference points for definition of commutating voltage (dv/dt).

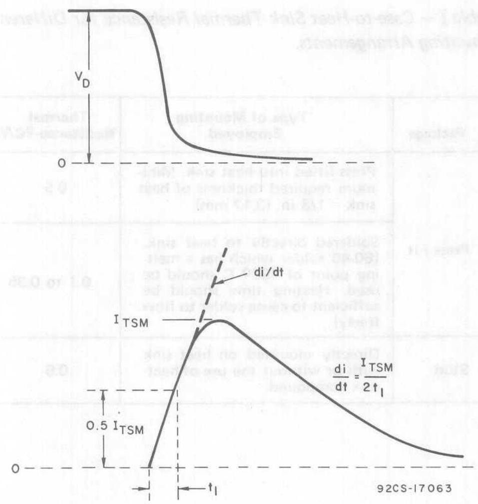


Fig. 15 – Rate of change of on-state current with time (defining di/dt).

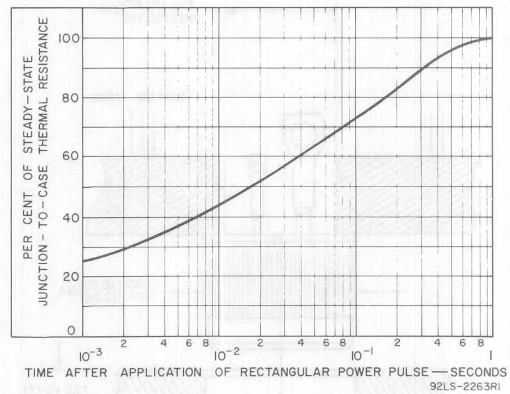


Fig. 16 – Transient junction-to-case thermal resistance vs. time.

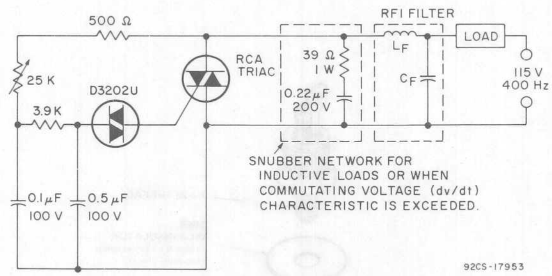


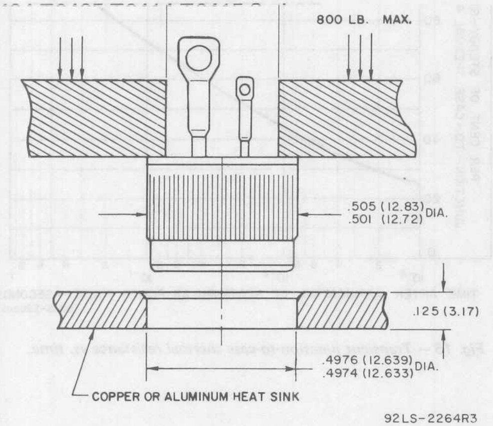
Fig. 17 – Typical phase-control circuit for operation at 400 Hz.

MOUNTING CONSIDERATIONS

Mounting of press-fit package types depends upon an interference fit between the thyristor case and the heat sink. As the thyristor is forced into the heat-sink hole, metal from the heat sink flows into the knurl voids of the thyristor case. The resulting close contact between the heat sink and the thyristor case assures low thermal and electrical resistances.

A recommended mounting method, shown in Fig. 18, shows press-fit knurl and heat-sink hole dimensions. If these dimensions are maintained, a "worst-case" condition of 0.0085 in. (0.2159 mm) interference fit will allow press-fit insertion below the maximum allowable insertion force of 800 pounds. A slight chamfer in the heat-sink hole will help center and guide the press-fit package properly into the heat sink. The insertion tool should be a hollow shaft having an inner diameter of 0.380 ± 0.010 in. (9.65 ± 0.254 mm) and an outer diameter of 0.500 in. (12.70 mm). These dimensions provide sufficient clearance for the leads and assure that no direct force will be applied to the glass seal of the thyristor.

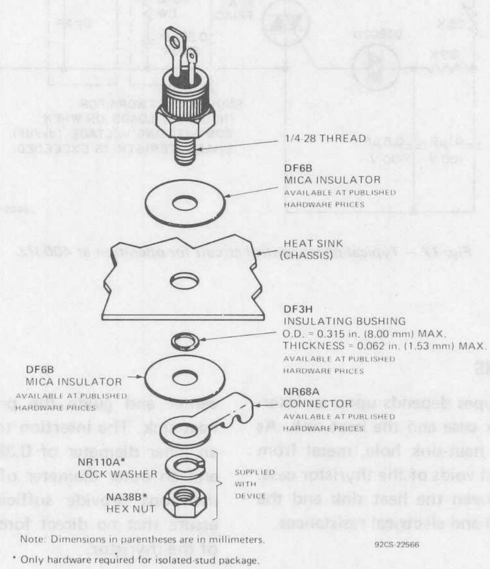
The press-fit package is not restricted to a single mounting arrangement; direct soldering and the use of epoxy adhesives have been successfully employed. The press-fit case is tin-plated to facilitate direct soldering to the heat sink. A 60-40 solder should be used and heat should be applied only long enough to allow the solder to flow freely.



NOTE: Dimensions in parentheses are in millimeters and are derived from the basic inch dimensions as indicated.

Fig. 18 – Suggested mounting method for press-fit package types.

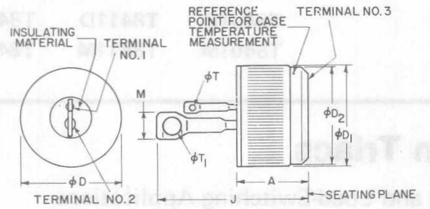
Package	Type of Mounting Employed	Thermal Resistance-°C/W
Press-Fit	Press-fitted into heat sink. Minimum required thickness of heat sink = 1/8 in. (3.17 mm)	0.5
	Soldered directly to heat sink. (60-40 solder which has a melting point of 188° C should be used. Heating time should be sufficient to cause solder to flow freely).	0.1 to 0.35
Stud	Directly mounted on heat sink with or without the use of heat-sink compound.	0.6



In the United Kingdom, Europe, Middle East, and Africa, mounting-hardware policies may differ; check the availability of all items shown with your RCA sales representative or supplier.

Fig. 19 – Suggested mounting arrangement for stud package types.

DIMENSIONAL OUTLINE FOR TYPES
T6404 & T6405 SERIES



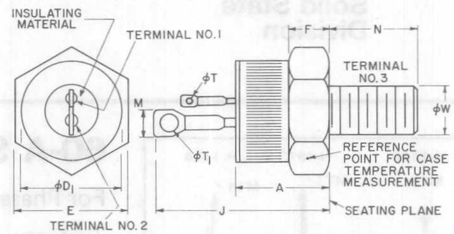
SYMBOL	INCHES MIN.	INCHES MAX.	MILLIMETERS MIN.	MILLIMETERS MAX.	NOTES
A	–	0.380	–	9.65	–
ϕD	0.501	0.510	12.73	12.95	–
ϕD_1	–	0.505	–	12.83	2
ϕD_2	0.465	0.475	11.81	12.07	–
J	0.825	1.000	20.95	25.40	–
M	0.215	0.225	5.46	5.71	1
ϕT	0.058	0.068	1.47	1.73	–
ϕT_1	0.138	0.148	3.51	3.75	–

NOTE 1: Contour and angular orientation of these terminals is optional.

NOTE 2: Outer diameter of knurled surface.

92CS-15207R2

DIMENSIONAL OUTLINE FOR TYPES
T6414 & T6415 SERIES



SYMBOL	INCHES MIN.	INCHES MAX.	MILLIMETERS MIN.	MILLIMETERS MAX.	NOTES
A	0.330	0.505	8.4	12.8	–
ϕD_1	–	0.544	–	13.81	–
E	0.544	0.562	13.82	14.28	–
F	0.113	0.200	2.87	5.08	3
J	0.950	1.100	24.13	27.94	–
M	0.215	0.225	5.46	5.71	1
N	0.422	0.453	10.72	11.50	–
ϕT	0.058	0.068	1.47	1.73	–
ϕT_1	0.138	0.148	3.51	3.75	–
ϕW	0.2225	0.2268	5.652	5.760	2

NOTE 1: Contour and angular orientation of these terminals is optional.

NOTE 2: Pitch diameter of 1/4-28 UNF-2A (coated) threads (ASA B1. 1-1960).

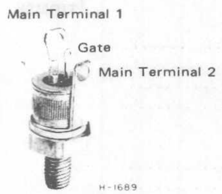
NOTE 3: A chamfer or undercut on one or both ends of hexagonal portion is optional.

92CS-15208R2

TERMINAL CONNECTIONS

No.1–Gate
No.2–Main Terminal 1
Case,No.3–Main Terminal 2

On special request, isolated-stud package triacs are also available.

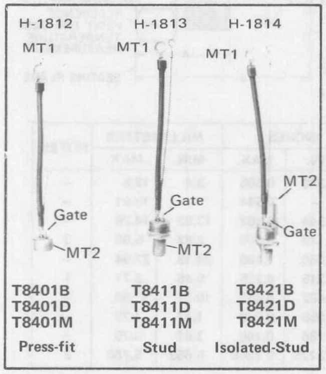


WARNING:
The RCA isolated-stud package thyristors should be handled with care. The ceramic portion of these thyristors contains BERYLLIUM OXIDE as a major ingredient. Do not crush, grind, or abrade these portions of the thyristors because the dust resulting from such action may be hazardous if inhaled.

RCA
Solid State Division

Thyristors

T8401B T8411B T8421B
T8401D T8411D T8421D
T8401M T8411M T8421M



60-A Silicon Triacs

For Phase-Control and Load-Switching Applications

Features:

- **di/dt Capability = 300 A/μs**
- **Shorted-Emitter, Center-Gate Design**
- **Low Switching Losses**
- **Low On-State Voltage at High Current Level**
- **Low Thermal Resistance**

Package \ Voltage	200 V	400 V	600 V
Press-fit	T8401B (41029)	T8401D (41030)	T8401M (41031)
Stud	T8411B (41032)	T8411D (41033)	T8411M (41034)
Iso-stud	T8421B (41035)	T8421D (41036)	T8421M (41037)

Numbers in parentheses (e.g. 41029) are former RCA type numbers

RCA T8401, T8411, and T8421 series triacs are gate-controlled, full-wave silicon ac switches with integral triggers. They are designed to switch from an off-state to an on-state for either polarity of applied voltage with positive or negative triggering voltages.

These triacs are intended for control of ac loads in applications such as heating controls motor controls, arc-welding equipment, light dimmers, and power switching systems. They can also be used in air-conditioning and photocopying equipment

MAXIMUM RATINGS, *Absolute-Maximum Values:*
For Operation with Sinusoidal Supply Voltage at Frequencies up to 50/60 Hz and with Resistive or Inductive Load.

		T8401B T8411B T8421B	T8401D T8411D T8421D	T8401M T8421M T8421M	
REPETITIVE PEAK OFF-STATE VOLTAGE:●	V_{DROM}				
Gate open, T_J = −40 to 110°C		200	400	600	V
RMS ON-STATE CURRENT (Conduction angle = 360°):	$I_{T(RMS)}$				
Case Temperature					
T_C = 85°C (Press-Fit types)			60		A
80°C (Stud types)			60		A
75°C (Isolated-Stud types)			60		A
For other conditions			See Fig. 3		
PEAK SURGE (NON-REPETITIVE) ON-STATE CURRENT:	I_{TSM}				
For one cycle of applied principal voltage					
60 Hz (sinusoidal)			600		A
50 Hz (sinusoidal)			500		A
For more than one cycle of applied principal voltage			See Fig. 4		
RATE OF CHANGE OF ON-STATE CURRENT:					
$V_{DM} = V_{DROM}$, I_{GT} = 300 mA, t_r = 0.1 μs (See Fig. 13)	di/dt		300		A/μs
FUSING CURRENT (for Triac Protection):					
T_J = −40 to 110°C, t = 1.25 to 10 ms	I^2t		1800		A^2s
PEAK GATE-TRIGGER CURRENT:■					
For 10 μs max. (See Fig. 7)	I_{GTM}		7		A
GATE POWER DISSIPATION (See Fig. 7):					
Peak (For 10 μs max., $I_{GTM} \leqslant$ 7 A (peak)	P_{GM}		42		W
AVERAGE	$P_{G(AV)}$		0.75		W
TEMPERATURE RANGE:▲					
Storage	T_{stg}		−40 to 150		°C
Operating (Case)	T_C		−40 to 110		°C
TERMINAL TEMPERATURE (During soldering):					
For 10 s max. (terminals and case)	T_T		225		°C
STUD TORQUE:	τ_s				
Recommended			125		in-lb
Maximum (DO NOT EXCEED)			150		in-lb

● For either polarity of main terminal 2 voltage (V_{MT2}) with reference to main terminal 1.
■ For either polarity of gate voltage (V_G) with reference to main terminal 1. ▲ For temperature measurement reference point, see Dimensional Outline.

11-73

ELECTRICAL CHARACTERISTICS *At Maximum Ratings Unless Otherwise Specified, and at Indicated Temperature*

CHARACTERISTIC	SYMBOL	LIMITS For All Types Except as Specified			UNITS
		MIN.	TYP.	MAX.	
Peak Off-State Current:● Gate open, V_{DROM} = Max. rated value	I_{DROM}	–	0.4	4	mA
Maximum On-State Voltage:● For i_T = 100 A (peak), T_C = 25°C	v_{TM}	–	1.55	1.8	V
DC Holding Current:● Gate open, Initial principal current = 500 mA (dc)					
v_D = 12 V, T_C = 25°C	I_{HO}	–	20	60	mA
T_C = −40°C		–	–	85	mA
For other case temperatures			See Fig. 6		
Critical Rate-of-Rise of Commutation Voltage:● For v_D = V_{DROM}, $I_{T(RMS)}$ = 60 A, commutating di/dt = 32 A/ms, gate unenergized, (See Fig. 14):	dv/dt				
T_C = 75°C (Press-fit types)		3	10	–	V/µs
= 65°C (Stud types)		3	10	–	
= 55°C (Isolated-stud types)		3	10	–	
Critical Rate-of-Rise of Off-State Voltage:● For v_D = V_{DROM}, exponential voltage rise, gate open, T_C = 110°C:	dv/dt				V/µs
T8401B, T8411B, T8421B		50	200	–	
T8401D, T8411D, T8421D		30	150	–	
T8401M, T8411M, T8421M		20	100	–	
DC Gate-Trigger Current:●■ Mode / V_{MT2} / V_G	I_{GT}				mA
For v_D = 12 V (dc), R_L = 30 Ω, T_C = 25°C: I+ positive positive		–	20	75	
III− negative negative		–	40	75	
I− positive negative		–	40	150	
III+ negative negative		–	100	150	
Mode / V_{MT2} / V_G					
For v_D = 12 V (dc), R_L = 30 Ω, T_C = −40°C: I+ positive positive		–	35	150	
III− negative negative		–	80	150	
I− positive negative		–	100	400	
III+ negative positive		–	280	400	
For other case temperatures			See Figs. 8 & 9		
DC Gate-Trigger Voltage:●■ For v_D = 12 V (dc), R_L = 30 Ω, T_C = 25°C	V_{GT}	–	1.35	2.8	V
For other case temperatures			See Fig. 10		
Gate-Controlled Turn-On Time: (Delay Time + Rise Time) For v_D = V_{DROM}, I_{GT} = 300 mA, t_r = 0.1 µs, i_T = 85 A (peak), T_C = 25°C (See Figs. 11 & 15)	t_{gt}	–	1.2	2.5	µs
Thermal Resistance, Junction-to-Case: Steady-State	$R_{\theta JC}$				°C/W
Press-fit types		–	–	0.3	
Stud types		–	–	0.35	
Isolated-stud types		–	–	0.4	
Transient (Press-fit & Stud types)			See Fig. 12		

● For either polarity of main terminal 2 voltage (V_{MT2}) with reference to main terminal 1.
■ For either polarity of gate voltage (V_G) with reference to main terminal 1.

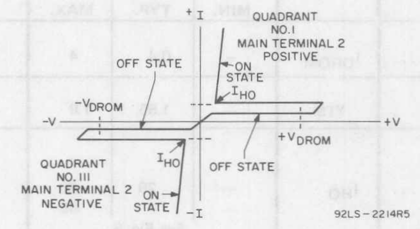


Fig. 1 — Principal voltage-current characteristic.

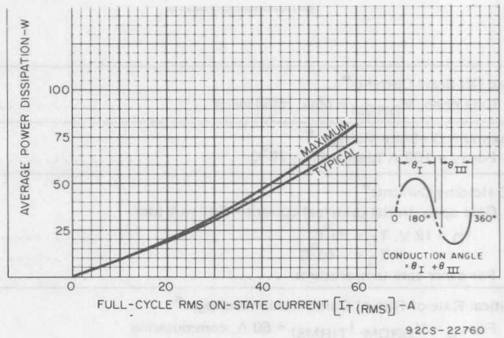


Fig. 2 — Power dissipation vs. on-state current.

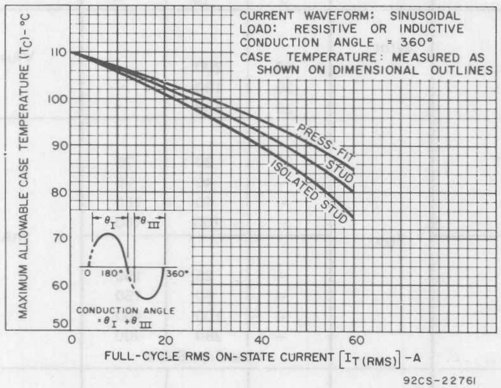


Fig. 3 — Maximum allowable case ten:perature vs. on-state current.

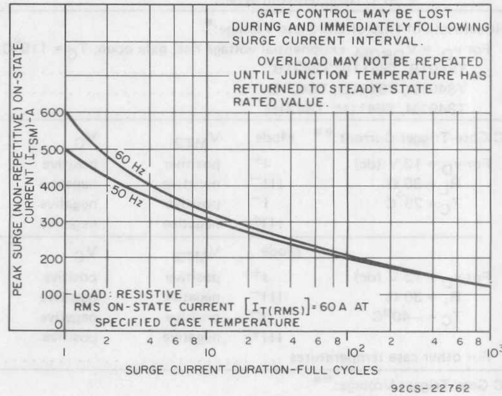


Fig. 4 — Peak surge on-state current vs. surge current duration.

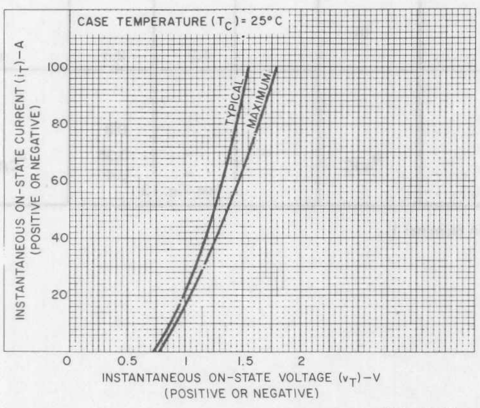


Fig. 5 — On-state current vs. on-state voltage.

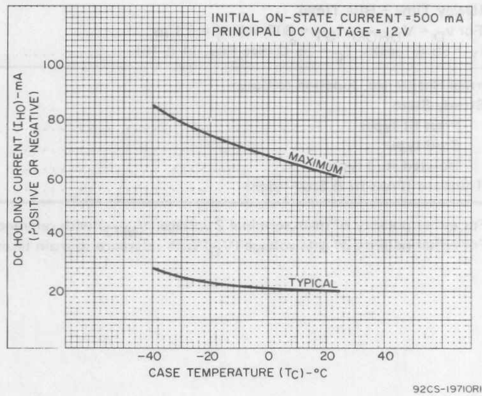


Fig. 6 — DC holding current vs. case temperature.

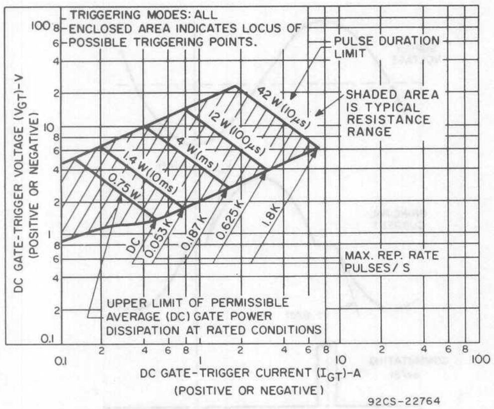


Fig. 7 — Gate-trigger characteristic and limiting conditions for determination of permissible gate-trigger pulses.

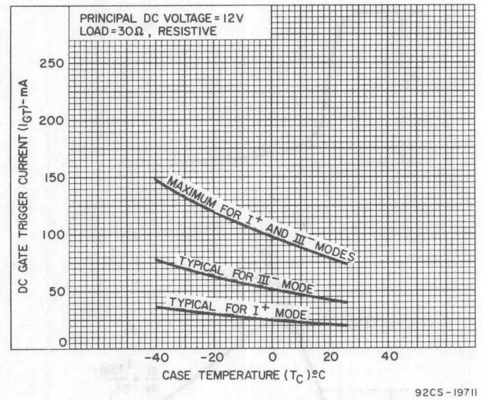


Fig. 8 — DC gate-trigger current vs. case temperature (I^+ and III^- modes).

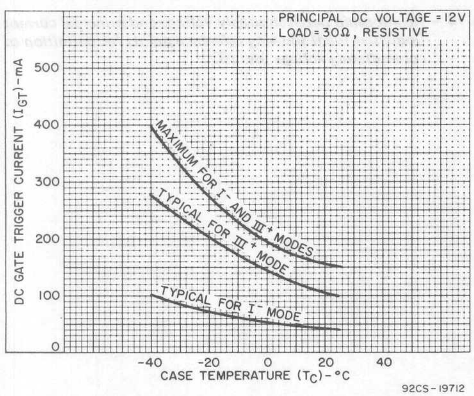


Fig. 9 — DC gate-trigger current vs. case temperature (I^- and III^+ modes).

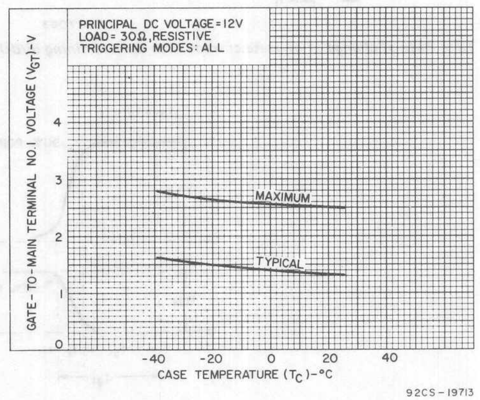


Fig. 10 — DC gate-trigger voltage vs. case temperature.

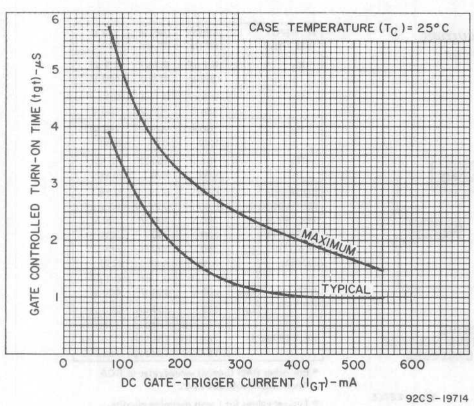


Fig. 11 — Turn on time vs. gate-trigger current.

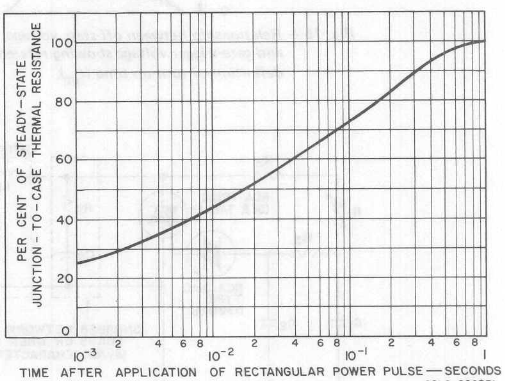


Fig. 12 — Transient junction-to-case thermal resistance vs. time.

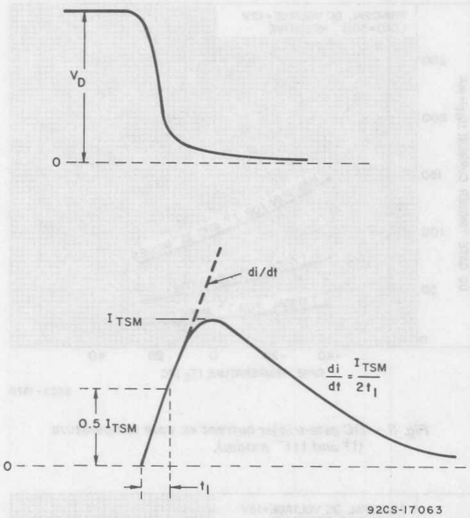


Fig. 13 – Rate-of-change of on-state current with time (defining di/dt).

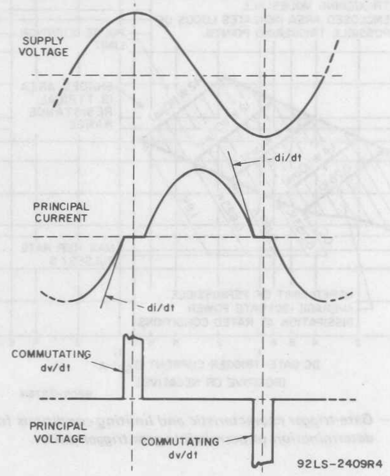


Fig. 14 – Relationship between supply voltage and principal current (inductive load) showing reference points for definition of commutating voltage (dv/dt).

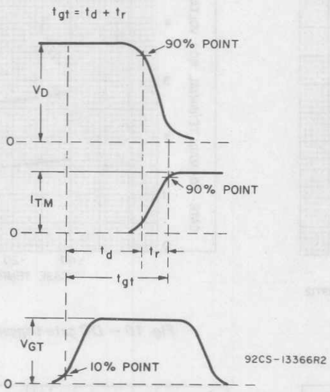
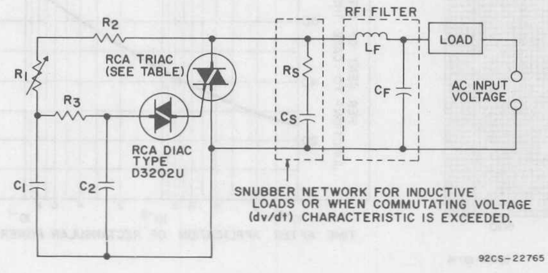


Fig. 15 – Relationship between off-state voltage, on-state current, and gate-trigger voltage showing reference points for definition of turn-on time (t_{gt}).



AC INPUT VOLTAGE		120 V 60 Hz	240 V 60 Hz	240 V 50 Hz
C_1		0.1 μF 200 V	0.1 μF 400 V	0.1 μF 400 V
C_2		0.1 μF 100 V	0.1 μF 100 V	0.1 μF 100 V
R_1		100 kΩ ½ W	200 kΩ ½ W	250 kΩ ½ W
R_3		15 kΩ ½ W	15 kΩ ½ W	15 kΩ ½ W
SNUBBER NETWORK FOR 60 A (RMS)● INDUCTIVE LOAD	C_S	0.18 0.22 μF 200 V	0.18 0.22 μF 400 V	0.18 0.22 μF 400 V
	R_S	330 390 Ω ½ W	330 390 Ω ½ W	330 390 Ω ½ W
RFI FILTER	C_F●	0.1 μF 200 V	0.1 μF 400 V	0.1 μF 400 V
	L_F●	100 μH	200 μH	200 μH
RCA TRIACS		T8401B T8411B T8421B	T8401D T8411D T8421D	T8401D T8411D T8421D

● For other RMS Current values refer to RCA Application Note AN-4745.

● Typical values for Lamp dimming circuits.

Fig. 16 – Typical phase-control circuit for lamp dimming, heat control, and universal-motor speed control.

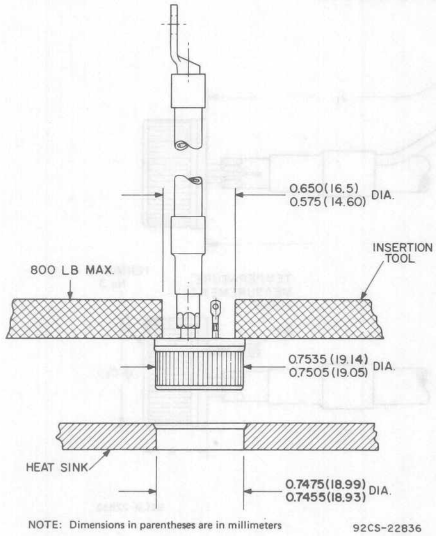
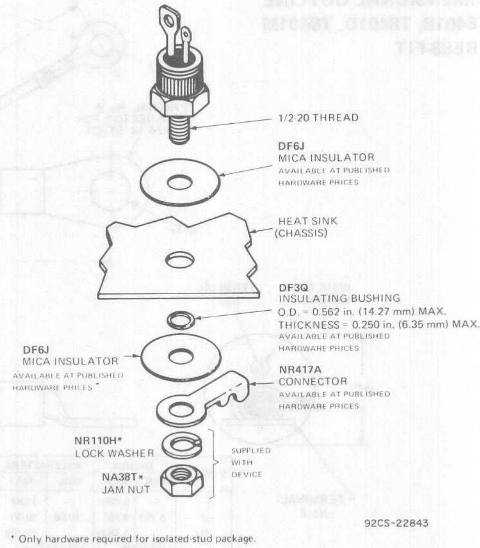


Fig. 17 – Mounting method for press-fit package types. Press-fit type mounting is not recommended for triacs operating at maximum rated rms current.



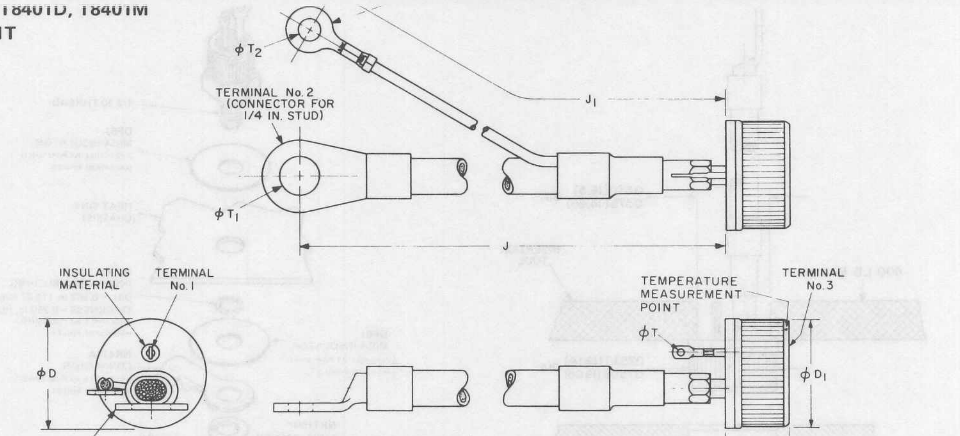
In the United Kingdom, Europe, Middle East, and Africa, mounting-hardware policies may differ; check the availability of all items shown with your RCA sales representative or supplier.

Fig. 18 – Suggested mounting arrangement for stud and isolated-stud package types.

Table I – Case-to-Heat Sink Thermal Resistance for Different Mounting Arrangements

Package	Type of Mounting Employed	Thermal Resistance °C/W
Press -Fit	Press-fitted into heat sink. Minimum required thickness of heat sink = 0.25 in. (6.35 mm)	0.4
	Soldered directly to heat sink. (60-40 solder which has a melting point of 188°C should be used. Heating time should be sufficient to cause solder to flow freely). THIS METHOD RECOMMENDED FOR MAXIMUM HEAT TRANSFER	0.012 to 0.036 For 1 to 3 mil thick solder layer
Stud	Directly mounted on heat sink with or without the use of heat sink compound.	0.05 to 0.15

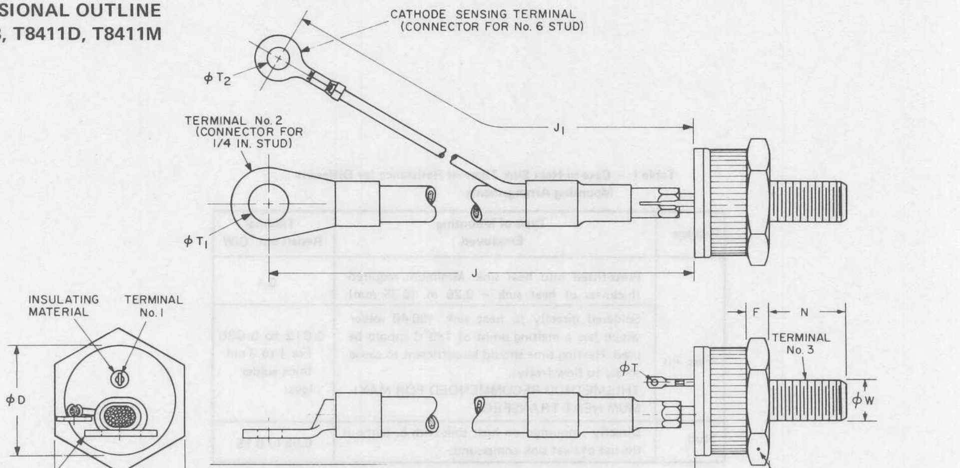
T8401B, T8401D, T8401M
PRESS-FIT

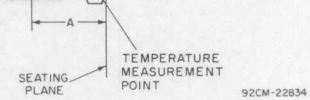


SYMBOL	INCHES		MILLIMETERS		NOTES
	MIN.	MAX.	MIN.	MAX.	
A	–	0.466	–	11.84	
φD	0.751	0.760	19.08	19.30	
φD_1	–	0.7535	–	19.139	
J	6.8 NOM.		172.72 NOM.		1
J_1	6.3 NOM.		160.02 NOM.		1
φT	0.060	0.065	1.52	1.65	
φT_1	0.266	–	6.75	–	
φT_2	0.144	–	3.70	–	

NOTE:
1: Leads J and J_1 available at various lengths. For information, contact the RCA Sales Office in your locale.

DIMENSIONAL OUTLINE
T8411B, T8411D, T8411M
STUD

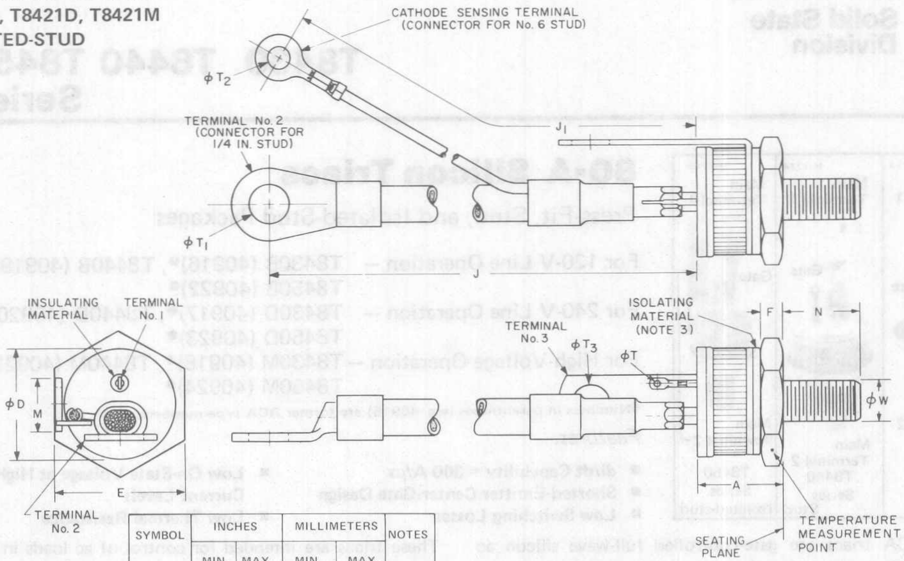




SYMBOL	INCHES		MILLIMETERS		NOTES
	MIN.	MAX.	MIN.	MAX.	
A	–	0.620	–	15.75	
φD	0.751	0.760	19.08	19.30	
E	0.866	0.872	21.99	22.14	
F	0.182	0.192	4.62	4.87	
J	6.8 NOM.		172.72 NOM.		1
J_1	6.3 NOM.		160.02 NOM.		1
N	0.740	0.760	18.79	19.30	
φT	0.060	0.065	1.52	1.65	
φT_1	0.266	–	6.75	–	
φT_2	0.144	–	3.70	–	
φW	½-20	NF-2A	½-20	NF-2A	2

NOTES:
1: Leads J and J_1 available at various lengths. For information, contact the RCA Sales Office in your locale.
2: φW is pitch diameter of coated threads. REF: Screw Thread Standard for Federal Services, Handbook H 28 Part I. Recommended torque: 125 inch-pounds.

DIMENSIONAL OUTLINE
T8421B, T8421D, T8421M
ISOLATED-STUD



SYMBOL	INCHES		MILLIMETERS		NOTES
	MIN.	MAX.	MIN.	MAX.	
A	–	0.710	–	18.03	
ϕD_1	0.751	0.760	19.08	19.30	
E	0.866	0.872	21.99	22.14	
F	0.182	0.192	4.62	4.87	
J	6.8 NOM.		172.72 NOM.		1
J_1	6.3 NOM.		160.02 NOM.		1
M	0.375	0.385	9.52	9.78	
N	0.740	0.760	18.79	19.30	
ϕT	0.060	0.065	1.52	1.65	
ϕT_1	0.266	–	6.75	–	
ϕT_2	0.144	–	3.70	–	
ϕT_3	0.195	0.205	4.95	5.20	
ϕW	½-20	NF-2A	½-20	NF-2A	2

NOTES:

1: Leads J and J_1 available at various lengths. For information, contact the RCA Sales Office in your locale.

2: ϕW is pitch diameter of coated threads. REF: Screw Thread Standards for Federal Services, Handbook H 28 Part I. Recommended torque: 125 inch-pounds

3: Isolating material (ceramic) between hex (stud) and terminal No. 3 is beryllium oxide.

92CM-22835

TERMINAL CONNECTIONS FOR ALL TYPES

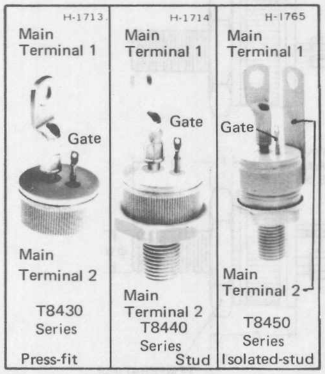
No. 1 – Gate
No. 2 – Main Terminal 1
Case, No. 3 – Main Terminal 2

WARNING: The ceramic of the isolated stud package contains beryllium oxide. Do not crush, grind, or abrade this part because the dust resulting from such action may be hazardous if inhaled, Disposal should be by burial.

RCA Solid State Division

Thyristors

T8430 T8440 T8450 Series



80-A Silicon Triacs

Press-Fit, Stud, and Isolated-Stud Packages

For 120-V Line Operation – T8430B (40916)•, T8440B (40919)•, T8450B (40922)•

For 240-V Line Operation – T8430D (40917)•, T8440D (40920)•, T8450D (40923)•

For High-Voltage Operation – T8430M (40918)•, T8440M (40921)•, T8450M (40924)•

•Numbers in parentheses (e.g. 40916) are former RCA type numbers.

Features:

- **di/dt Capability = 300 A/μs**
- **Shorted-Emitter Center-Gate Design**
- **Low Switching Losses**
- **Low On-State Voltage at High Current Levels**
- **Low Thermal Resistance**

These RCA triacs are gate-controlled full-wave silicon ac switches. They are designed to switch from an off-state to an on-state for either polarity of applied voltage with positive or negative gate triggering voltages.

These triacs are intended for control of ac loads in applications such as heating controls, motor controls, arc-welding equipment, light dimmers, and power switching systems. They can also be used in air-conditioning and photocopying equipment.

MAXIMUM RATINGS, *Absolute-Maximum Values:*
For Operation with Sinusoidal Supply Voltage at Frequencies up to 50/60 Hz and with Resistive or Inductive Load.

		T8430B T8440B T8450B	T8430D T8440D T8450D	T8430M T8440M T8450M	
REPETITIVE PEAK OFF-STATE VOLTAGE:*					
Gate open, T_J = –40 to 110°C	V_{DROM}	200	400	600	V
RMS ON-STATE CURRENT (Conduction Angle = 360°):	$I_{T(RMS)}$				
Case temperature					
T_C = 75°C (Press-Fit types)			80		A
65°C (Stud types)			80		A
55°C (Isolated-Stud types)			80		A
For other conditions			See Fig. 3		
PEAK SURGE (NON-REPETITIVE) ON-STATE CURRENT:	I_{TSM}				
For one cycle of applied principal voltage					
60 Hz (sinusoidal)			850		A
50 Hz (sinusoidal)			720		A
For more than one cycle of applied principal voltage			See Fig. 4		
RATE-OF-CHANGE OF ON-STATE CURRENT:	di/dt				
$V_{DM} = V_{DROM}$, I_{GT} = 300 mA, t_r = 0.1μs *(See Fig. 13)*			300		A/μs
FUSING CURRENT (for Triac Protection):	I^2t				
T_J = –40 to 110°C, t = 1.25 to 10 ms			3600		A^2s
PEAK GATE-TRIGGER CURRENT: ■	I_{GTM}				
For 10μs max. *(See Fig. 7)*			7		A
GATE POWER DISSIPATION:					
Peak (For 10μs max., $I_{GTM} \leq$ 7A (peak), *(See Fig. 7)*	P_{GM}		40		W
Average	$P_{G(AV)}$		0.75		W
TEMPERATURE RANGE:▲					
Storage	T_{stg}		-40 to 150		°C
Operating (Case)	T_C		-40 to 110		°C
TERMINAL TEMPERATURE (During soldering):	T_T				
For 10 s max. (terminals and case)			225		°C

Formerly RCA Dev. Nos. TA7752–TA7757, and TA7937–TA7939, respectively.

*For either polarity of main terminal 2 voltage (V_{MT2}) with reference to main terminal 1.

■For either polarity of gate voltage (V_G) with reference to main terminal 1.

▲For temperature measurement reference point, see Dimensional Outline.

CHARACTERISTIC	SYMBOL	OTHERWISE SPECIFIED MIN.	TYP.	MAX.	UNITS
Peak Off-State Current:♠ Gate open, $T_J = 110^\circ C$, V_{DROM} = Max. rated value. .	I_{DROM}	–	0.4	4	mA
Maximum On-State Voltage:♠ For i_T = 200 A (peak), $T_C = 25^\circ C$	V_{TM}	–	1.7	2	V
DC Holding Current:♠ Gate open, Initial principal current = 500 mA (dc), v_D = 12V: $T_C = 25^\circ C$ . . . . $= -40^\circ C$	I_{HO}	– –	20 –	60 85	mA
For other case temperatures			See *Fig. 6*		
Critical Rate-of-Rise of Commutation Voltage:♠ For $v_D = V_{DROM}$, $I_{T(RMS)}$ = 80 A, commutating di/dt = 42 A/ms, gate unenergized, (See *Fig. 14*): $T_C = 75^\circ C$ (Press-fit types) . . . . $= 65^\circ C$ (Stud types) . . . . $= 55^\circ C$ (Isolated-stud types)	dv/dt	3 3 3	10 10 10	– – –	V/μs
Critical Rate-of-Rise of Off-State Voltage:♠ For $v_D = V_{DROM}$, exponential voltage rise, gate open, $T_C = 110^\circ C$: T8430B, T8440B, T8450B . . . . T8430D, T8440D, T8450D . . . . T8430M, T8440M, T8450M.	dv/dt	50 30 20	200 150 100	– – –	V/μs
DC Gate-Trigger Current:♠♦ Mode V_{MT2} V_G For v_D = 12 V (dc) I+ positive positive $R_L = 30\ \Omega$ III- negative negative $T_C = 25^\circ C$ I- positive negative III+ negative negative	I_{GT}	– – – –	20 40 40 100	75 75 150 150	mA
Mode V_{MT2} V_G For v_D = 12 V (dc) I+ positive positive $R_L = 30\Omega$ III- negative negative $T_C = -40^\circ C$ I- positive negative III+ negative positive		– – – –	35 80 100 280	150 150 400 400	
For other case temperatures			See *Figs. 8 & 9*		
DC Gate-Trigger Voltage:♠♦ For v_D = 12 V (dc), $R_L = 30\ \Omega$, $T_C = 25^\circ C$	V_{GT}	–	1.35	2.5	V
For other case temperatures			See *Fig. 10*		
Gate-Controlled Turn-On Time: (Delay Time + Rise Time) For $v_D = V_{DROM}$, I_{GT} = 300 mA, t_r = 0.1 μs, i_T = 112 A (peak), $T_C = 25^\circ C$ (See *Figs. 11 & 15*) . . .	t_{gt}	–	1.2	2.5	μs
Thermal Resistance, Junction-to-Case: Steady-State Press-fit types . . . . Stud types. . . . . Isolated-stud types	$R_{\theta JC}$	– – –	– – –	0.3 0.4 0.5	°C/W
Transient (Press-fit & Stud types)			See *Fig. 12*		

♠ For either polarity of main terminal 2 voltage (V_{MT2}) with reference to main terminal 1.
♦ For either polarity of gate voltage (V_G) with reference to main terminal 1.

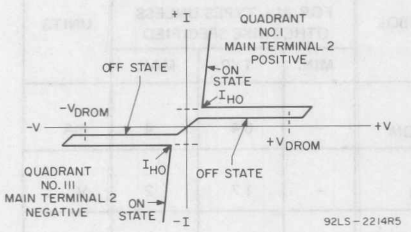


Fig. 1 – Principal voltage-current characteristic.

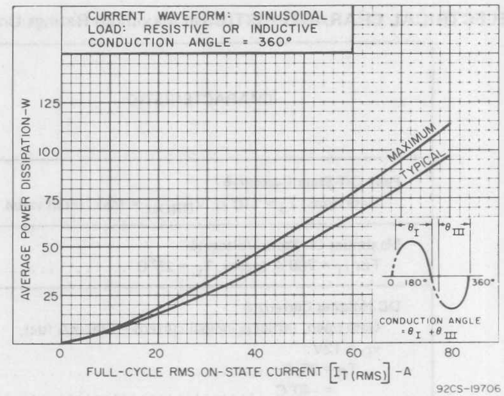


Fig. 2 – Power dissipation vs. on-state current.

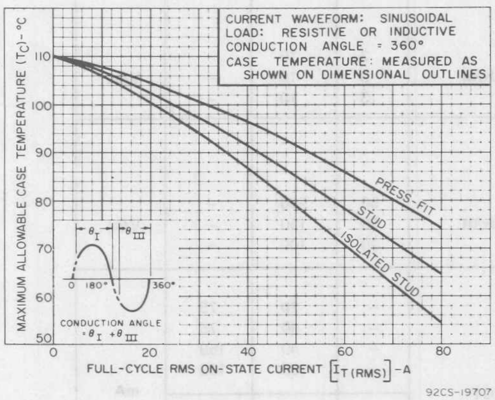


Fig. 3 – Maximum allowable case temperature vs. on-state current.

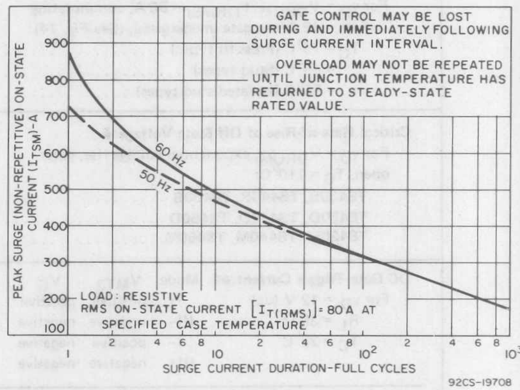


Fig. 4 – Peak surge on-state current vs. surge current duration.

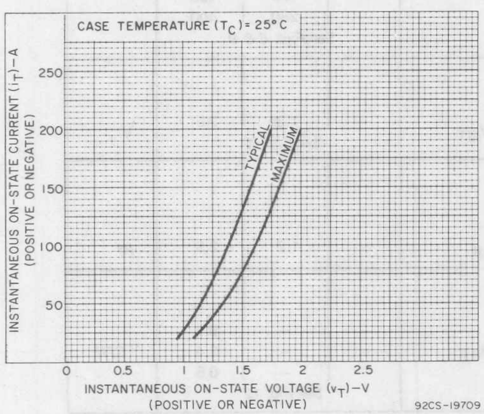


Fig. 5 – On-state current vs. on-state voltage.

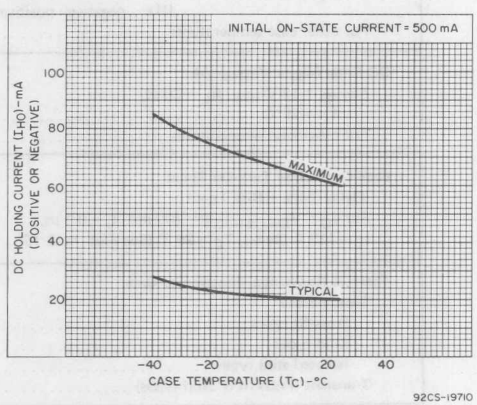


Fig. 6 – DC holding current vs. case temperature.

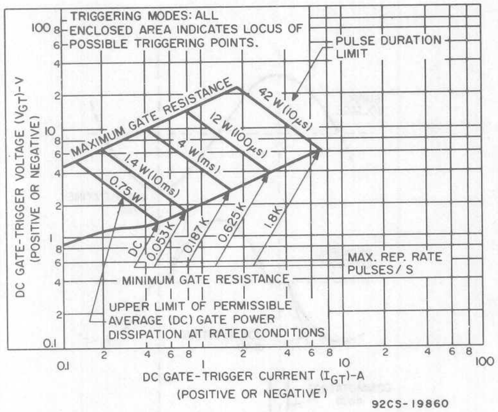


Fig. 7 — Gate-trigger characteristics and limiting conditions for determination of permissible gate-trigger pulses.

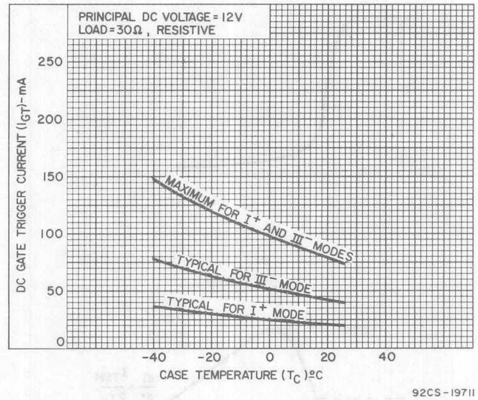


Fig. 8 — DC gate-trigger current vs. case temperature (I^+ & III^- modes).

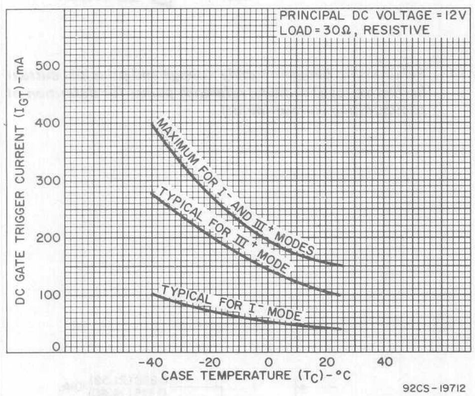


Fig. 9 — DC gate-trigger current vs. case temperature (I^- & III^+ modes).

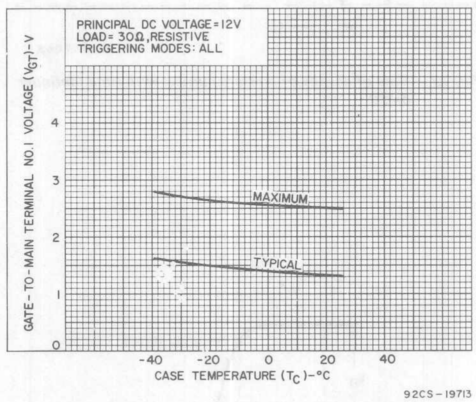


Fig. 10 — DC gate-trigger voltage vs. case temperature.

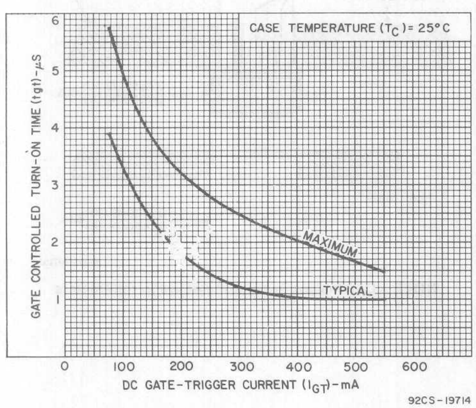


Fig. 11 — Turn-on time vs. gate-trigger current.

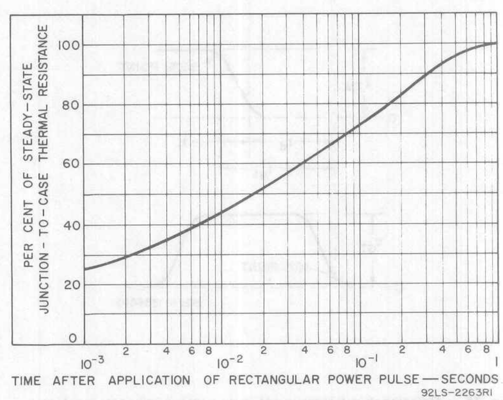


Fig. 12 — Transient junction-to-case thermal resistance vs. time.

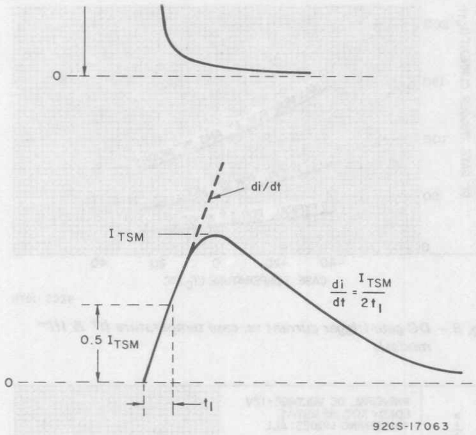


Fig. 13 – Rate of change of on-state current with time (defining di/dt).

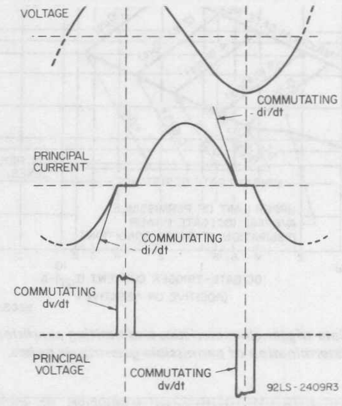


Fig. 14 – Relationship between supply voltage and principal current (inductive load) showing reference points for definition of commutating voltage (dv/dt).

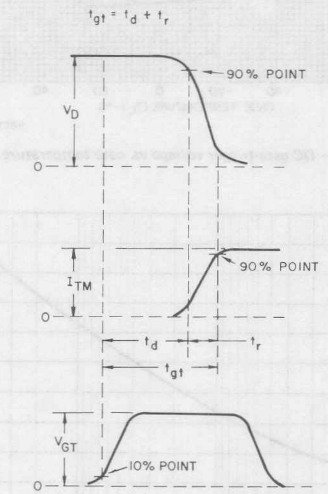
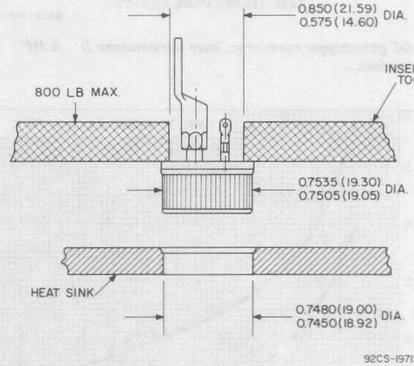


Fig. 15 – Relationship between off-state voltage, on-state current, and gate-trigger voltage showing reference points for definition of turn-on time (t_{gt}).



NOTE: Dimensions in parentheses are in millimeters

Fig. 16 – Suggested mounting method for press-fit package types.

Mounting of press-fit package types depends upon an interference fit between the thyristor case and the heat sink. As the thyristor is forced into the heat-sink hole, metal from the heat sink flows into the knurl voids of the thyristor case. The resulting close contact between the heat sink and the thyristor case assures low thermal and electrical resistances.

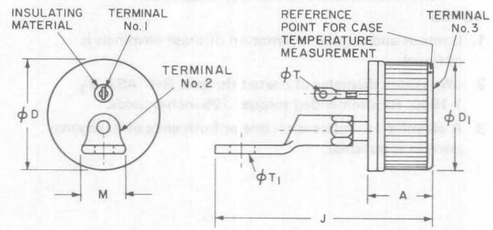
A recommended mounting method, shown in Fig. 16, shows press-fit knurl and heat-sink hole dimensions. If these dimensions are maintained, a "worst-case" condition of 0.0085 in. (0.2159 mm) interference fit will allow press-fit insertion below the maximum allowable insertion force of 800 pounds. A slight chamfer in the heat-sink hole will help center and guide the press-fit package properly into the heat sink. The insertion tool should be a hollow shaft having an inner diameter of 0.575 in. (14.60 mm) and an outer diameter of 0.850 in. (21.59 mm). These dimensions provide sufficient clearance for the leads and assure that no direct force will be applied to the glass seal of the thyristor.

The press-fit package is not restricted to a single mounting arrangement; direct soldering has been successfully employed. The press-fit case is tin-plated to facilitate direct soldering to the heat sink. A 60-40 solder should be used and heat should be applied only long enough to allow the solder to flow freely.

Table I – Case-to-Heat-Sink Thermal Resistance for Different Mounting Arrangements.

Package	Type of Mounting Employed	Thermal Resistance-°C/W
Press-Fit	Press-fitted into heat sink. Minimum required thickness of heat sink = 0.25 in. (6.35 mm)	0.4
	Soldered directly to heat sink. (60-40 solder which has a melting point of 188°C should be used. Heating time should be sufficient to cause solder to flow freely).	0.15 to 0.3
Stud	Directly mounted on heat sink with or without the use of heat-sink compound.	0.2 to 0.4

DIMENSIONAL OUTLINE FOR T8430 SERIES PRESS-FIT



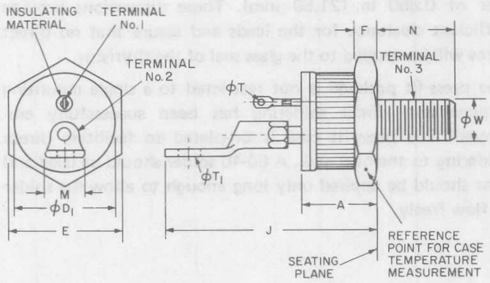
92CS-17666R1

SYMBOL	INCHES		MILLIMETERS		NOTES
	MIN.	MAX.	MIN.	MAX.	
A	–	0.454	–	11.53	
ϕD	0.751	0.760	19.08	19.30	
ϕD_1	–	0.7585	–	19.13	2
J	–	1.53	–	38.86	
M	0.375	0.385	9.52	9.78	1
ϕT	0.060	0.065	1.52	1.65	
ϕT_1	–	0.193	–	4.90	

NOTES

1. Contour and angular orientation of these terminals is optional.
2. Outer diameter of knurled surface.

DIMENSIONAL OUTLINE FOR T8440 SERIES STUD



92CS-17667R1

SYMBOL	INCHES		MILLIMETERS		NOTES
	MIN.	MAX.	MIN.	MAX.	
A	–	0.591	–	15.01	
ϕD_1	0.751	0.760	19.08	19.30	
E	0.866	0.872	21.99	22.14	
F	0.182	0.192	4.62	4.87	3
J	–	1.63	–	41.40	
M	0.375	0.385	9.52	9.78	1
N	0.740	0.760	18.79	19.30	
ϕT	0.060	0.065	1.52	1.65	
ϕT_1	–	0.193	–	4.90	
ϕW	½–20	NF–2A	½–20	NF–2A	2

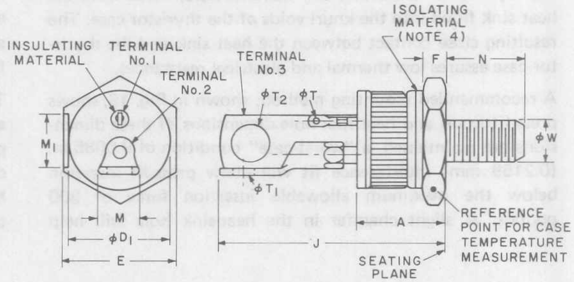
NOTES

1. Contour and angular orientation of these terminals is optional.
2. ϕW is pitch diameter of coated threads. Ref: ASA B_1, 1-1960. Recommended torque: 125 inch-pounds.
3. A chamfer or undercut on one or both ends of hexagonal portion is optional.

TERMINAL CONNECTIONS FOR ALL TYPES

No. 1 – Gate
No. 2 – Main Terminal 1
Case, No. 3 – Main Terminal 2

DIMENSIONAL OUTLINE FOR T8450 SERIES ISOLATED-STUD



92CS-19705

SYMBOL	INCHES		MILLIMETERS		NOTES
	MIN.	MAX.	MIN.	MAX.	
A	–	0.789	–	20.04	
ϕD_1	0.751	0.760	19.08	19.30	
E	0.866	0.872	21.99	22.14	
F	0.182	0.192	4.62	4.87	3
J	–	1.85	–	46.99	
M	0.375	0.385	9.52	9.78	1
M_1	0.375	0.385	9.52	9.78	1
N	0.740	0.760	18.79	19.30	
ϕT	0.060	0.065	1.52	1.65	
ϕT_1	–	0.193	–	4.90	
ϕT_2	0.195	0.205	4.95	5.20	
ϕW	½–20	NF–2A	½–20	NF–2A	2

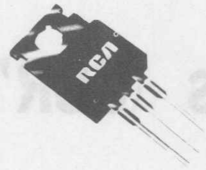
NOTES

1. Contour and angular orientation of these terminals is optional.
2. ϕW is pitch diameter of coated threads, REF: ASA B1, 1-1960. Recommended torque: 125 inch-pounds.
3. A chamfer or undercut on one or both ends of hexagonal portion is optional.
4. Isolating material (ceramic) between hex (stud) and terminal No. 3 is beryllium oxide.

WARNING: The ceramic of the isolated stud package contains beryllium oxide. Do not crush, grind, or abrade this part because the dust resulting from such action may be hazardous if inhaled. Disposal should be by burial.

Silicon Controlled Rectifiers (SCR's)

S2062 Series



JEDEC TO-220AB

H-1535R1

4-Ampere Sensitive-Gate Silicon Controlled Rectifiers

For Power Switching and Control Applications

Features:

- **Microampere gate sensitivity**
- **Minimum gate current specified for the S2062 series**
- **600-V capability**
- **4-A (rms) on-state current ratings**
- **35-A peak surge capability**
- **Glass-passivated chip for stability**
- **Low thermal resistances**
- **Surge capability curve**

The S2060, S2061, and S2062 series● are sensitive-gate silicon controlled rectifiers designed for switching ac and dc currents. These SCR's are divided into the three different series according to gate sensitivity. The types within each series differ in their voltage ratings; the voltage ratings are identified by suffix letters in the type designations. (Cont'd on pg. 2)

● Formerly the RCA106, RCA107, and RCA108 series.

MAXIMUM RATINGS, *Absolute-Maximum Values:*

		Suffix Letter Q	Y	F	A	B	C	D	E	M	
NON-REPETITIVE PEAK REVERSE VOLTAGE $R_{GK} = 1000\ \Omega$, $T_C = -40$ to $110°C$	V_{RSXM}	25	50	75	125	250	400	500	600	700	V
NON-REPETITIVE PEAK OFF-STATE VOLTAGE $R_{GK} = 1000\ \Omega$, $T_C = -40$ to $110°C$	V_{DSXM}										
REPETITIVE PEAK REVERSE VOLTAGE $R_{GK} = 1000\ \Omega$, $T_C = -40$ to $110°C$	V_{RRXM}	15	30	50	100	200	300	400	500	600	V
REPETITIVE PEAK OFF-STATE VOLTAGE $R_{GK} = 1000\ \Omega$, $T_C = -40$ to $110°C$	V_{DRXM}										

		All types	
ON-STATE CURRENT: Conduction angle = 180°, $T_C = 85°C$			
Average ac value	$I_{T(AV)}$	2.5	A
RMS value	$I_{T(RMS)}$	4	A
DC operation	$I_{T(DC)}$	2.75	A
PEAK SURGE (NON-REPETITIVE) ON-STATE CURRENT: For one cycle of applied principal voltage 60 Hz (sinusoidal)	I_{TSM}	35	A
For more than one cycle of applied principal voltage		See Fig. 6	
PEAK GATE CURRENT ($t = 10\ \mu sec$)	I_{GFM}	0.2	A
PEAK GATE REVERSE VOLTAGE	V_{GRM}	6	V
RATE OF CHANGE OF ON-STATE CURRENT: $V_{DM} = V_{DROM}$, $I_{GT} = 1$ mA, $t_r = 0.5\ \mu s$, $T_C = 110°C$	di/dt	100	A/μs
GATE POWER DISSIPATION:			
PEAK FORWARD (for 10 μs max.)	P_{GM}	0.5	W
AVERAGE (averaging time = 10 ms max.)	$P_{G(AV)}$	0.1	W
TEMPERATURE RANGE:			
Storage	T_{stg}	-40 to +150	°C
Operating (case)*	T_C	-40 to +110	°C
TERMINAL TEMPERATURE (During soldering): For 10 s max.	T_T	250	°C

*Temperature measuring point is shown in the dimensional outline.

11-73

All types in each series utilize the JEDEC TO-220AB package. Upon request, each type is available in either of two variants of the TO-220AB package. For information on these package variations, contact the RCA Sales Office in your locale.

These thyristors have microampere gate-current requirements which permit operation with low-level logic circuits. They can be used for lighting, power-switching, and motor-speed controls, and for gate-current amplification for driving larger SCR's.

ELECTRICAL CHARACTERISTICS

CHARACTERISTIC	SYMBOL	LIMITS FOR ALL TYPES UNLESS OTHERWISE SPECIFIED			UNITS
		MIN.	TYP.	MAX.	
PEAK OFF-STATE CURRENT:					
Forward, $V_D = V_{DRXM}$, $R_{GK} = 1000\ \Omega$	I_{DRXM}				
$T_C = 25^oC$		–	0.1	10	μA
$T_C = 110^oC$		–	10	100	μA
Reverse, $V_R = V_{RRXM}$, $R_{GK} = 1000\ \Omega$	I_{RRXM}				
$T_C = 25^oC$		–	0.1	10	μA
$T_C = 100^oC$		–	10	100	μA
INSTANTANEOUS ON-STATE VOLTAGE: For i_T = 4 A and $T_C = 25^oC$ (See Fig. 16)	v_T	–	1.25	2.2	V
DC GATE TRIGGER CURRENT: V_D = 12 V (dc), $R_L = 30\ \Omega$, $T_C = 25^oC$:	I_{GT}				
S2060 Series		–	–	200	μA
S2061 Series		–	–	500	μA
S2062 Series		100	–	2000	μA
For other case temperatures		See Figs. 10,11,12			
DC GATE TRIGGER VOLTAGE: V_D = 12 V (dc), $R_L = 30\ \Omega$, $T_C = 25^oC$	V_{GT}	–	0.5	0.8	V
For other case temperatures		See Fig. 14			
INSTANTANEOUS HOLDING CURRENT: $R_{GK} = 1000\ \Omega$, V_D = 12 V, $I_{T\ (INITIAL)}$ = 50 mA, $T_C = 25^oC$:	i_H				
S2060 Series		–	1.7	3	mA
S2061 Series		–	3.9	6	mA
S2062 Series		–	6	10	mA
LATCHING CURRENT: $R_{GK} = 1000\ \Omega$, V_D = 12 V, $T_C = 25^oC$:	i_L				
S2060 Series (I_{GT} = 200 μA)		–	1.8	4	mA
S2061 Series (I_{GT} = 500 μA)		–	2.5	8	mA
S2062 Series (I_{GT} = 2000 μA)		–	8	12	mA
CRITICAL RATE OF RISE OF OFF-STATE VOLTAGE: $V_D = V_{DRXM}$, $R_{GK} = 1000\ \Omega$, Exponential rise, $T_C = 110^oC$	dv/dt	5	8	–	V/μs
GATE-CONTROLLED TURN-ON TIME: $V_D = V_{DRXM}$, i_T = 1 A, $R_{GK} = 1000\ \Omega$, I_{GT} = 1 mA, rise time = 0.1 μs, $T_C = 25^oC$	t_{gt}	–	1.7	2.5	μs
CIRCUIT COMMUTATED TURN-OFF TIME: $V_D = V_{DRXM}$, i_T = 1 A, $R_{GK} = 1000\ \Omega$, Pulse Duration = 50 μs, dv/dt = 5 V/μs, di/dt = –10 A/μs, I_{GT} = 1 mA at turn on, $T_C = 110^oC$ . . .	t_q	–	30	100	μs
THERMAL RESISTANCE:					
Junction-to-Case*	$R_{\theta JC}$	–	–	3.5	$^oC/W$
Junction-to-Ambient	$R_{\theta JA}$	–	–	60	$^oC/W$

* Temperature measuring point is shown in the dimensional outline

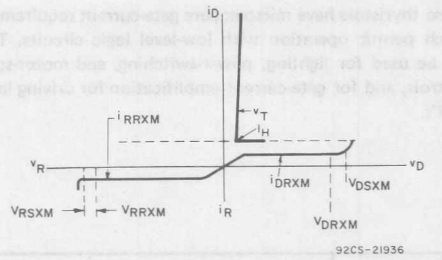


Fig. 1—Typical volt-ampere characteristics for all series.

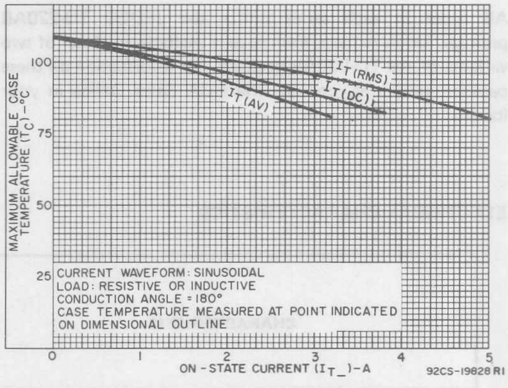


Fig. 2—Maximum allowable case temperature vs. on-state-current for all series.

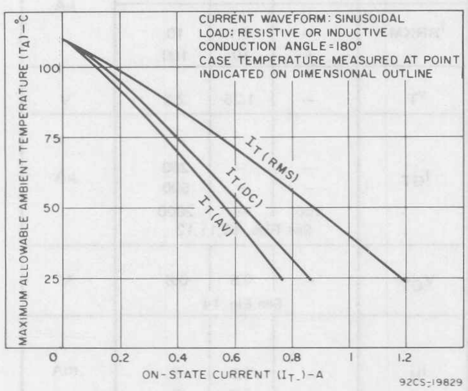


Fig. 3—Maximum allowable ambient temperature vs. on-state current for all series.

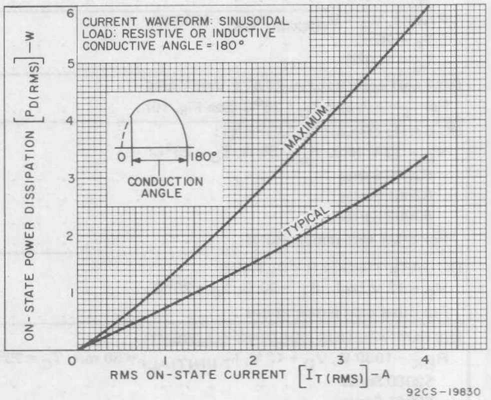


Fig. 4—Power dissipation vs. rms-on-state current for all series.

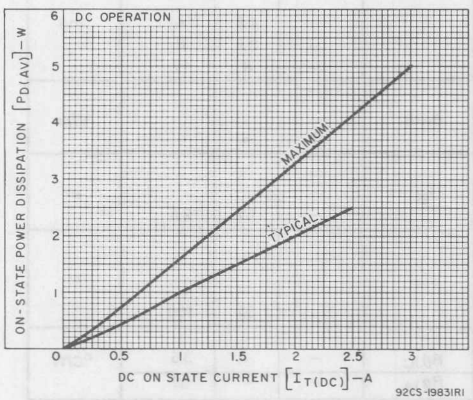


Fig. 5—Power dissipation vs. dc on-state current for all series.

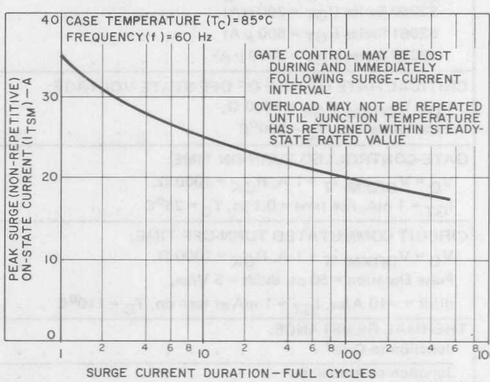


Fig. 6—Peak surge on-state current vs. surge-current duration for all series.

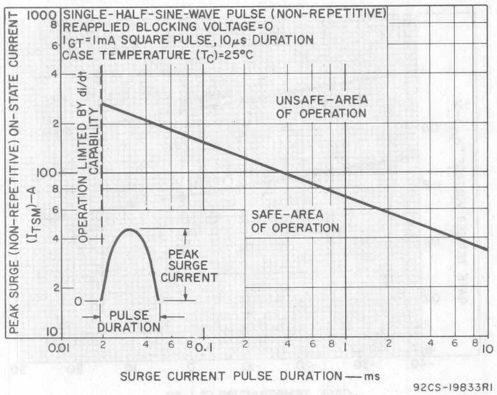


Fig. 7—Surge capability without reapplied blocking voltage for all series.

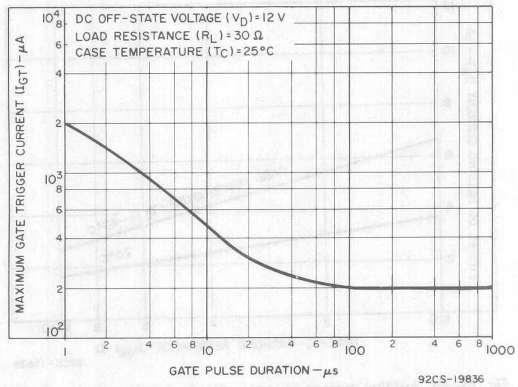


Fig. 8—Maximum gate trigger current vs. gate pulse duration for types in the S2060 series.

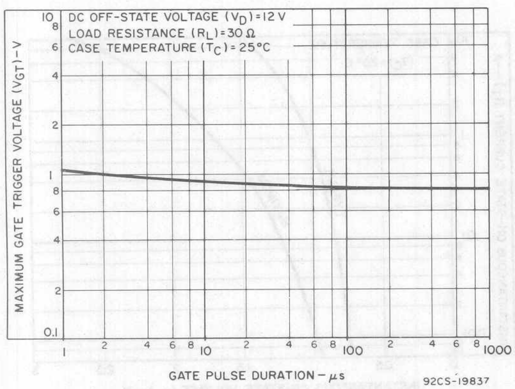


Fig. 9—Maximum gate trigger voltage vs. gate pulse duration for types in the S2060 series.

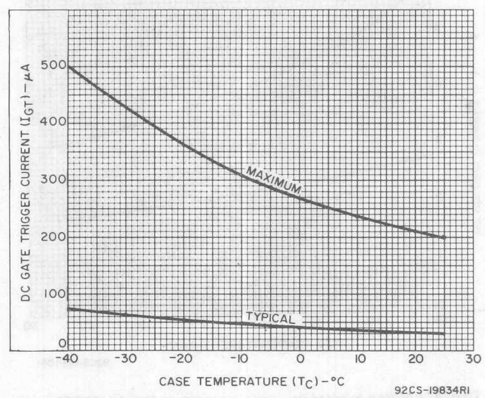


Fig. 10—DC gate trigger current vs. case temperature for S2060 series.

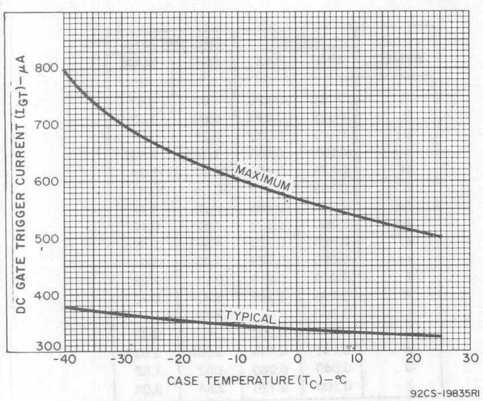


Fig. 11—DC gate trigger current vs. case temperature for S2061 series.

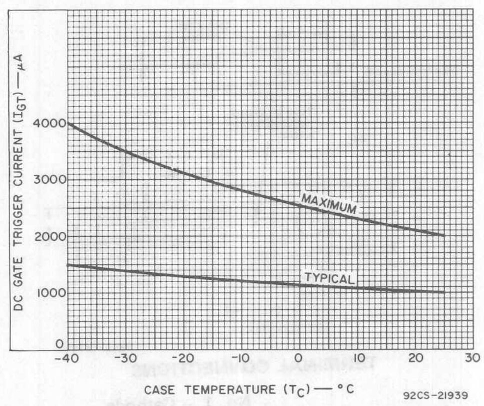


Fig. 12—DC gate trigger current vs. case temperature for S2062 series.

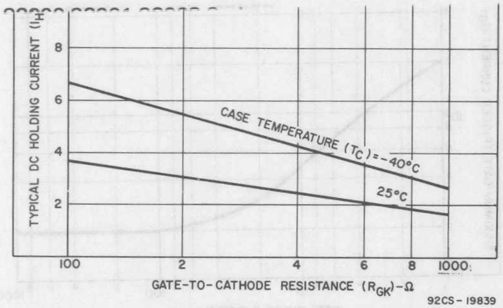


Fig. 13—DC holding current vs. gate-cathode resistance for the S2060 series.

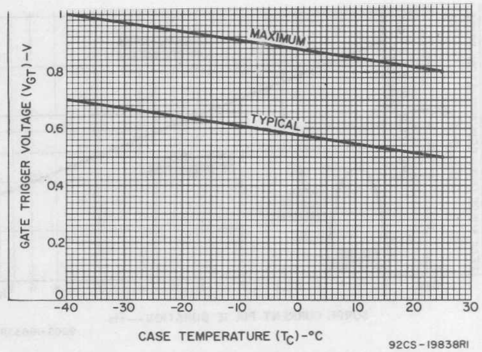


Fig. 14—Gate trigger voltage vs. case temperature for all series.

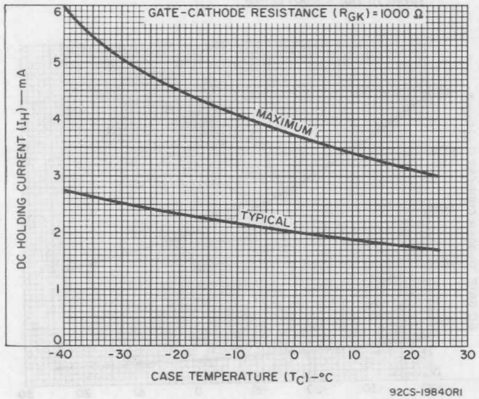


Fig. 15—DC holding current vs. case temperature for the S2060 series.

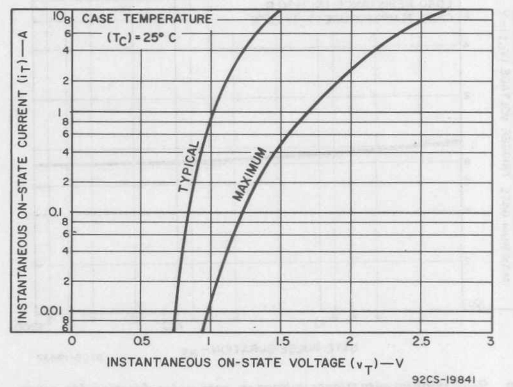
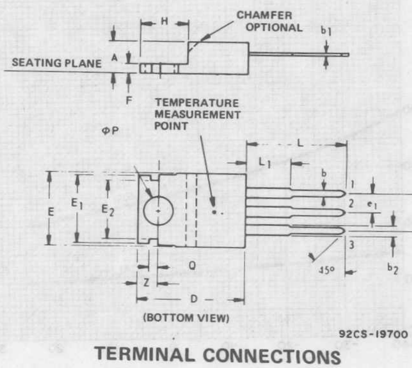


Fig. 16—Instantaneous on-state current vs. on-state voltage for all series.

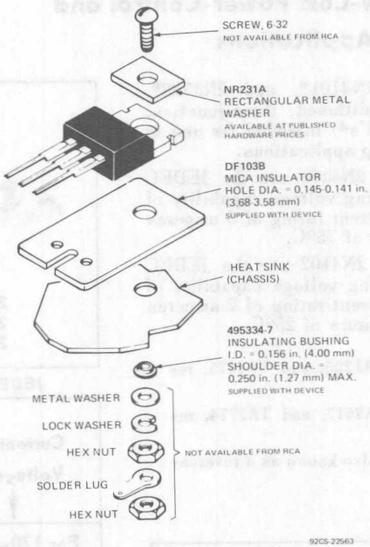
DIMENSIONAL OUTLINE (JEDEC TO-220AB)



SYMBOL	INCHES MIN.	INCHES MAX.	MILLIMETERS MIN.	MILLIMETERS MAX.
A	0.160	0.190	4.07	4.82
b	0.025	0.040	0.64	1.02
b_1	0.012	0.020	0.31	0.51
b_2	0.045	0.055	1.143	1.397
D	0.575	0.600	14.61	15.24
E	0.395	0.410	10.04	10.41
E_1	0.365	0.385	9.28	9.77
E_2	0.300	0.320	7.62	8.12
e	0.180	0.220	4.57	5.58
e_1	0.080	0.120	2.03	3.04
F	0.020	0.055	0.51	1.39
H	0.235	0.265	5.97	6.73
L	0.500	–	12.70	–
L_1	–	0.250	–	6.35
φP	0.141	0.145	3.582	3.683
Q	0.040	0.060	1.02	1.52
Z	0.100	0.120	2.54	3.04

TERMINAL CONNECTIONS

No. 1 – Cathode
Mounting Flange, No. 2 – Anode
No. 3 – Gate



In the United Kingdom, Europe, Middle East, and Africa, mounting-hardware policies may differ; check the availability of all items shown with your RCA sales representative or supplier.

Suggested mounting hardware.

RCA
Solid State
Division

Thyristors

2N3228 2N3529
2N3525 2N4101
2N3528 2N4102

All-Diffused SCR's for Low-Cost Power-Control and Power-Switching Applications

RCA 2N3228*, 2N3525*, 2N4101*, and 2N3528●, 2N3529●, and 2N4102● are all-diffused, three-junction, silicon controlled-rectifiers (SCR's▲) intended for use in power-control and power-switching applications.

Types 2N3228, 2N3525, and 2N4101 use the JEDEC TO-66 package and have a blocking voltage capability of up to 600 volts and a forward current rating of 5 amperes (rms value) at a case temperature of 75°C.

Types 2N3528, 2N3529, and 2N4102 use the JEDEC TO-8 package and have a blocking voltage capability of up to 600 volts and a forward current rating of 2 amperes (rms value) at an ambient temperature of 25°C.

* Formerly Dev. Types TA1222, TA1225, and TA2773, respectively.

● Formerly Dev. Types TA2597, TA2617, and TA2774, respectively.

▲ The silicon controlled-rectifier is also known as a reverse-blocking triode thyristor.

2N3228
2N3525
2N4101

JEDEC TO-66

2N3528
2N3529
2N4102

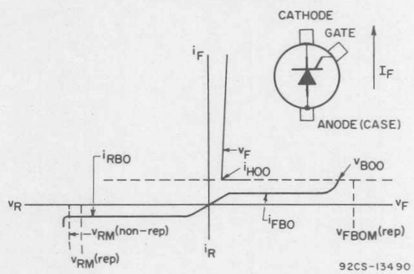
JEDEC TO-8

Current → / Voltage ↓	Average Forward Amperes 3.2	Average Forward Amperes 1.3
For 120-Volt Line Operation	2N3228	2N3528
For 240-Volt Line Operation	2N3525	2N3529
For High-Voltage Power Supplies	2N4101	2N4102

FEATURES

- Designed especially for high-volume systems
- Readily adaptable for printed-circuit boards and metal heat sinks
- Low switching losses
- High di/dt and dv/dt capabilities
- Shorted emitter gate-cathode construction
- Forward and reverse gate dissipation ratings
- All-diffused construction – assures exceptional uniformity and stability of characteristics
- Direct-soldered internal construction – assures exceptional resistance to fatigue
- Symmetrical gate-cathode construction – provides uniform current density, rapid electrical conduction, and efficient heat dissipation
- All-welded construction and hermetic sealing
- Low leakage currents, both forward and reverse
- Low forward voltage drop at high current levels
- Low thermal resistance

TYPICAL E-I CHARACTERISTIC OF SILICON CONTROLLED-RECTIFIER



Absolute-Maximum Ratings, for Operation with Sinusoidal AC Supply Voltage at a Frequency between 50 and 400 Hz, and with Resistive or Inductive Load

RATINGS	CONTROLLED-RECTIFIER TYPES						UNITS
	2N3228	2N3525	2N4101	2N3528	2N3529	2N4102	
Transient Peak Reverse Voltage (Non-Repetitive), v_{RM}(non-rep)[a]	330	660	700	330	660	700	volts
Peak Reverse Voltage (Repetitive), v_{RM}(rep)[b]	200	400	600	200	400	600	volts
Peak Forward Blocking Voltage (Repetitive), v_{FBOM}(rep)[c]	600	600	700	600	600	700	volts
Forward Current:							
For case temperature (T_C) of + 75°C, and unit mounted on heat sink–							
Average DC value at a conduction angle of 180°, I_{FAV}[d]	3.2	3.2	3.2	—	—	—	amperes
RMS value, I_{FRMS}[e]	5.0	5.0	5.0	—	—	—	amperes
For other conditions, See Fig. 8							
For free-air temperature (T_{FA}) of 25°C, and with no heat sink employed–							
Average DC value at a conduction angle of 180°, I_{FAV}[d]	—	—	—	1.3	1.3	1.3	amperes
RMS value, I_{FRMS}[e]	—	—	—	2.0	2.0	2.0	amperes
For other conditions, See Fig. 9.							
Peak Surge Current, i_{FM}(surge)[f]:							
For one cycle of applied voltage		60			60		amperes
For more than one cycle of applied voltage		See Fig. 13			See Fig. 13		
Sub-Cycle Surge (Non-Repetitive) I^2t[g]							
For a period of 1 ms to 8.3 ms		15			15		ampere² second
Rate of Change of Forward Current, di/dt[h]		200			200		amperes/ microsecond
V_{FB} = v_{BOO}(min. value) I_{GT} = 200 mA, 0.5 μs rise time (See waveshapes of Fig. 1)							
Gate Power*:							
Peak, Forward or Reverse, for 10 μs duration, P_{GM}[j] (See Figs. 5 and 6)		13			13		watts
Average, P_{GAV}[k]		0.5			0.5		watt
Temperature:							
Storage, T_{stg}		-40 to +125			-40 to +125		°C
Operating (Case), T_C		-40 to +100			-40 to +100		°C

*Any values of peak gate current or peak gate voltage to give the maximum gate power is permissible.

WAVESHAPE OF di/dt RATING TEST

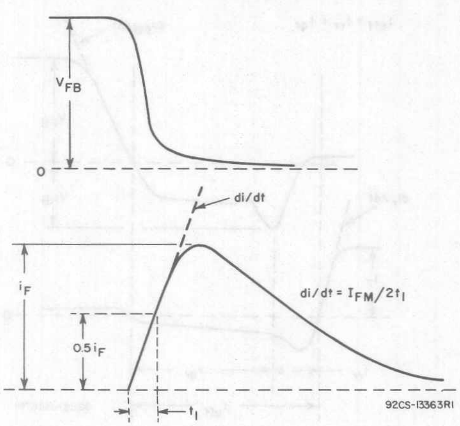


Fig. 1

WAVESHAPE OF CRITICAL dv/dt RATING TEST

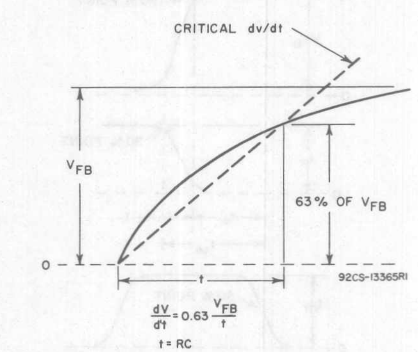


Fig. 2

CHARACTERISTICS	CONTROLLED-RECTIFIER TYPES									UNITS
	2N3228, 2N3528			2N3525, 2N3529			2N4101, 2N4102			
	Min.	Typ.	Max.	Min.	Typ.	Max.	Min.	Typ.	Max.	
Forward Breakover Voltage, v_{BOO}[m]: At T_C = +100°C	200	—	—	400	—	—	600	—	—	volts
Peak Blocking Current, at T_C = +100°C: Forward, I_{FBOM}[n] (V_{FBO}[p] = v_{BOO} (min. value))	—	0.10	1.5	—	0.20	3.0	—	0.40	4.0	mA
Reverse, I_{RBOM}[q] (V_{RBO}[p] = v_{RM} (rep) value)	—	0.05	0.75	—	0.10	1.5	—	0.20	2.0	mA
Forward Voltage Drop, v_{F}: At a Forward Current of 30 amperes and a T_C = +25°C (See Fig. 11)	—	2.15	2.8	—	2.15	2.8	—	2.15	2.8	volts
DC Gate-Trigger Current, I_{GT}[s]: At T_C = +25°C (See Fig. 5)	—	8	15	—	8	15	—	8	15	mA(dc)
Gate-Trigger Voltage, V_{GT}[t]: At T_C = +25°C (See Fig. 5)	—	1.2	2.0	—	1.2	2.0	—	1.2	2.0	volts(dc)
Holding Current, i_{HOO}[u]: At T_C = +25°C	—	10	20	—	10	20	—	10	20	mA
Critical Rate of Applied Forward Voltage, Critical dv/dt[v] (V_{FB} = v_{BOO} (min. value), exponential rise, T_C = +100°C (See waveshape of Fig. 2))	10	200	—	10	200	—	10	200	—	volts/microsecond
Turn-On Time, t_{on}[w], (Delay Time + Rise Time) (V_{FB} = v_{BOO} (min. value), i_F = 4.5 amperes, I_{GT} = 200mA, 0.1 μs rise time, T_C = +25°C (See waveshapes of Fig. 3))	0.75	1.5	—	0.75	1.5	—	0.75	1.5	—	microseconds
Turn-Off Time, t_{off}[x], (Reverse Recovery Time + Gate Recovery Time) (i_F = 2 amperes, 50 μs pulse width, dv_{FB}/dt = 20 v/μs, di_r/dt = 30 A/μs, I_{GT} = 200mA, T_C = +75°C (See waveshapes of Fig. 4))	—	15	50	—	15	50	—	15	50	microseconds

CHARACTERISTICS	2N3228, 2N3525, 2N4101			2N3528, 2N3529, 2N4102			UNITS
	Min.	Typ.	Max.	Min.	Typ.	Max.	
Thermal Resistance:							
Junction-to-case	—	—	4	—	—	—	°C/W
Junction-to-ambient	—	—	—	—	—	40	°C/W

WAVESHAPE OF t_{on} RATING TEST

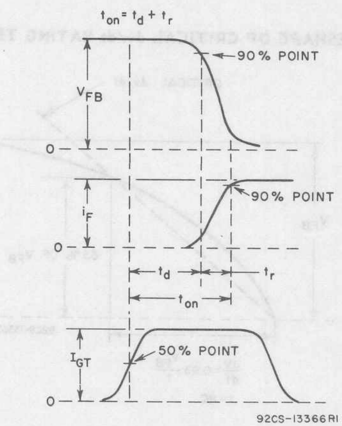


Fig. 3

WAVESHAPE OF t_{off} RATING TEST

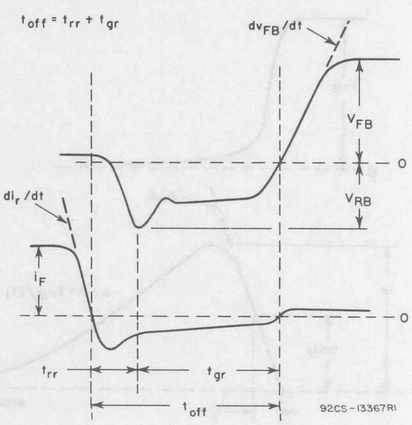


Fig. 4

FORWARD GATE CHARACTERISTICS

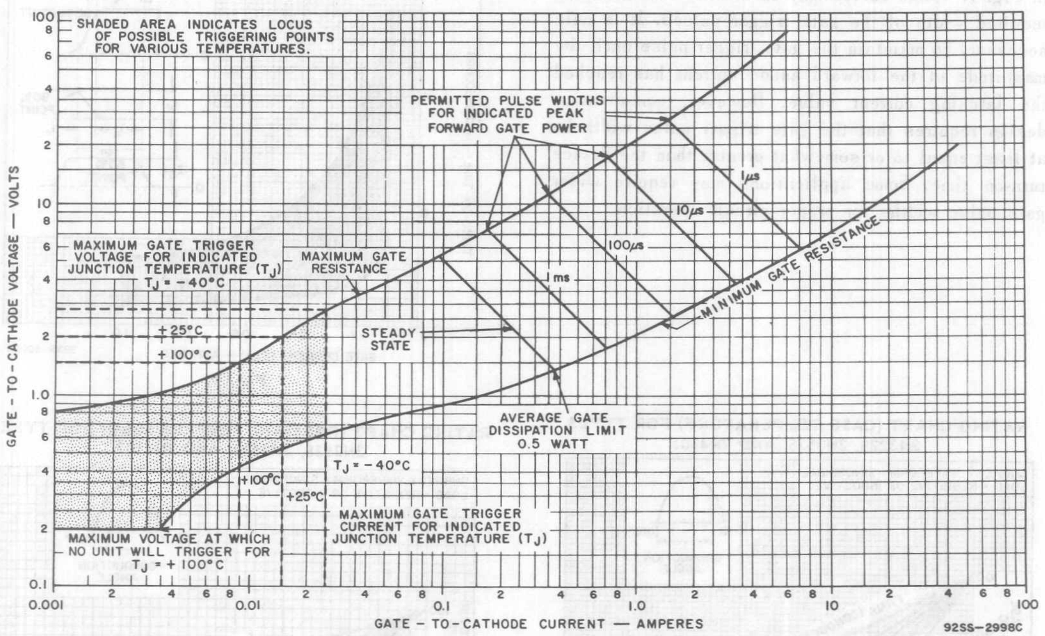


Fig. 5

REVERSE GATE CHARACTERISTICS

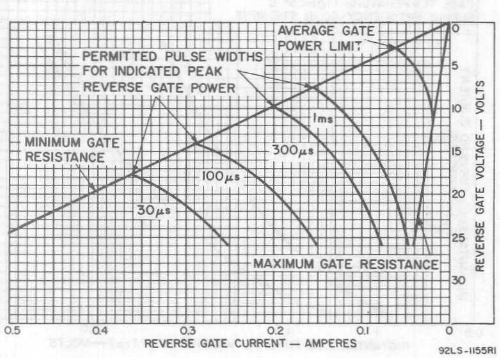


Fig. 6

TRIGGERING CONSIDERATIONS

The construction of the gate-cathode junction used in these devices provides a large periphery center gate. These devices also employ shorted-emitter construction which removes restrictions on both forward and reverse peak gate voltage and peak gate current. Limiting values of volt-ampere products for different gate pulse widths are shown in Fig. 5. These limits should be adhered to when designing pulse trigger circuits for maximum trigger pulse widths and peak power dissipation. The volt-ampere products in the reverse direction shown in Fig. 6 should be used to determine limitations for reverse gate transients or reverse gate pulses if present. In all cases, total average gate dissipation, both forward and reverse, should not exceed the average gate dissipation rating (P_{GAV}) of 0.5 watt.

Turn-on times for different gate currents are shown in Fig. 7. These curves may be used to determine the required width of the gate trigger pulses. It is only necessary to maintain the gate trigger pulse until the magnitude of the forward anode current has reached the latching current value. However, conservative design requires that the gate trigger pulse width be at least equal to or somewhat greater than the device turn-on time. Some applications may require wider gate pulse widths for proper circuit operation.

TURN-ON TIME CHARACTERISTICS

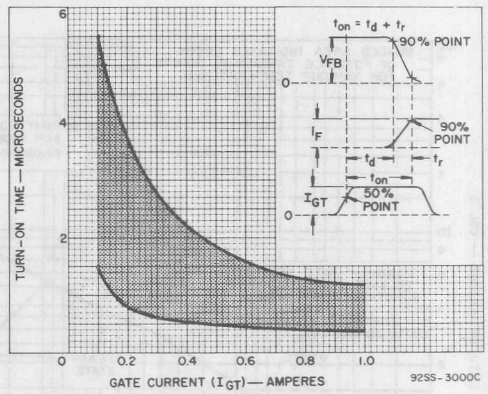


Fig. 7

RATING CHART (CASE TEMPERATURE) FOR TYPES 2N3228, 2N3525, AND 2N4101

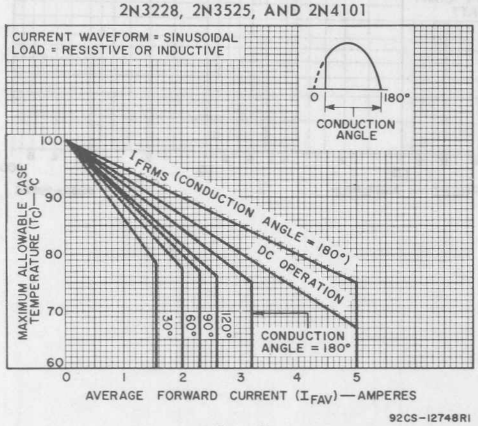


Fig. 8

RATING CHART (FREE-AIR TEMPERATURE) FOR TYPES 2N3528, 2N3529, AND 2N4102

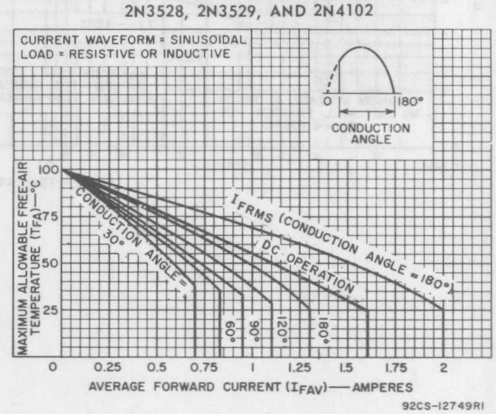


Fig. 9

POWER DISSIPATION CHART FOR ALL TYPES

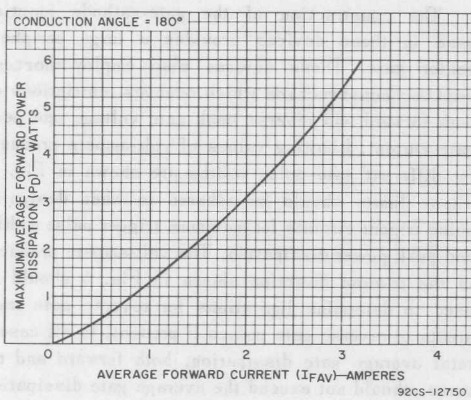


Fig. 10

FORWARD CHARACTERISTICS FOR ALL TYPES

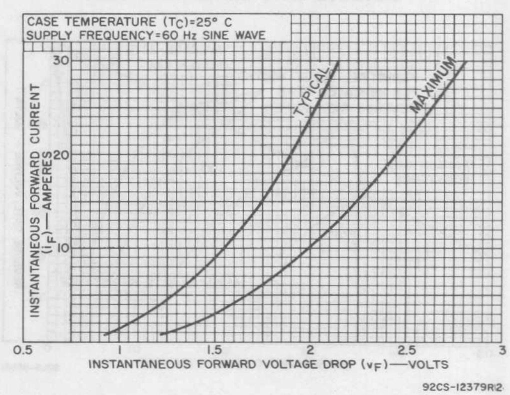


Fig. 11

OPERATION GUIDANCE CHART FOR TYPES 2N3228, 2N3525, AND 2N4101

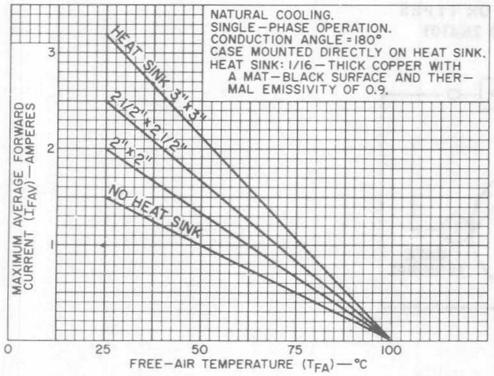


Fig. 12

SURGE CURRENT RATING CHART

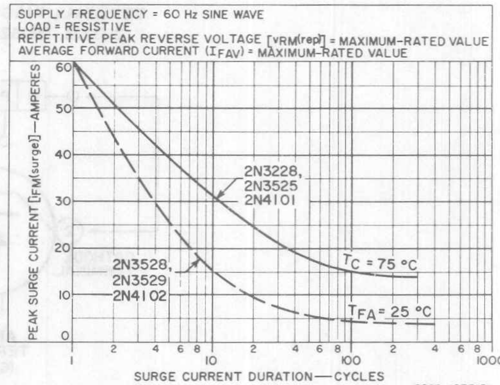
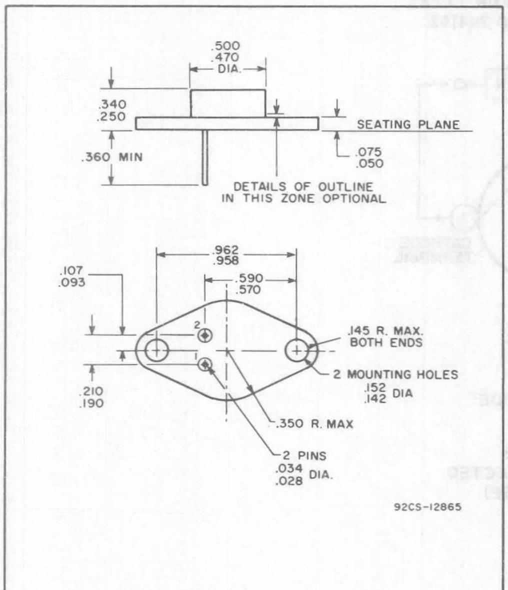


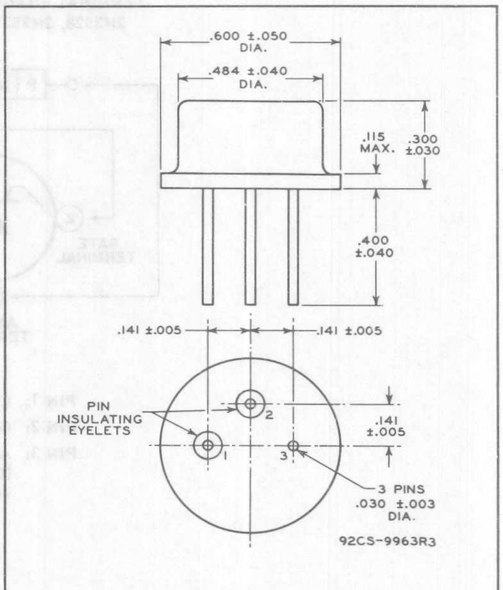
Fig. 13

DIMENSIONAL OUTLINE FOR TYPES 2N3228, 2N3525, AND 2N4101 JEDEC No. TO-66



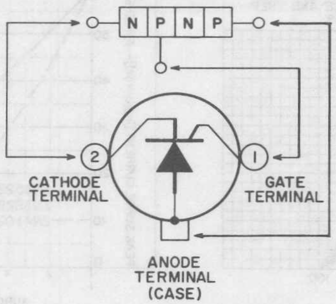
DIMENSIONS IN INCHES

DIMENSIONAL OUTLINE FOR TYPES 2N3528, 2N3529, AND 2N4102 JEDEC No. TO-8



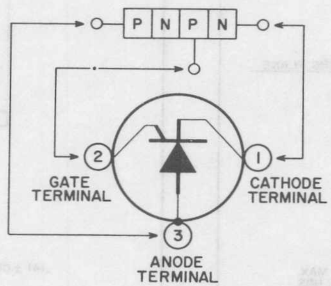
DIMENSIONS IN INCHES

TERMINAL DIAGRAM FOR TYPES
2N3228, 2N3525, AND 2N4101



PIN 1: GATE
PIN 2: CATHODE
CASE: ANODE

TERMINAL DIAGRAM FOR TYPES
2N3528, 2N3529, AND 2N4102



PIN 1: CATHODE
PIN 2: GATE
PIN 3: ANODE (CONNECTED TO CASE)

RCA Solid State Division

Thyristors

S2400 Series

JEDEC TO-8

4.5-Ampere Silicon Controlled Rectifiers For Capacitive-Discharge Systems

For Low-Voltage Operation – S2400A (40942)*
For 120-V Line Operation – S2400B (40943)*
For 240-V Line Operation – S2400D (40944)*
For High-Voltage Operation – S2400M (40945)*

*Numbers in parentheses (e.g. 40942) are former RCA type numbers.

Features:

- **200-A surge current capability**
- **Low switching losses**
- **High di/dt and dv/dt capabilities**
- **Shorted-emitter gate-cathode construction**
- **Forward and reverse gate-dissipation ratings**
- **Low forward voltage drop at high current levels**

These RCA types are all-diffused silicon controlled rectifiers (reverse-blocking triode thyristors) designed for high-peak-current low-average-current applications. Typical applications are ignition service, crowbars, and other capacitive-discharge systems.

These SCR's have an rms on-state current rating ($I_{T[RMS]}$) of 4.5 amperes and have voltage ratings (V_{DROM}) of 100, 200, 400, and 600 volts.

MAXIMUM RATINGS, *Absolute-Maximum Values:*

	Symbol	S2400A	S2400B	S2400D	S2400M	Units
Non-repetitive peak reverse voltage▲						
Gate open	V_{RSOM}	100	200	400	600	V
Non-repetitive peak forward voltage▲						
Gate open	V_{DSOM}	150	250	500	700	V
Repetitive peak reverse voltage▲						
Gate open	V_{RROM}	100	200	400	600	V
Repetitive peak off-state voltage▲						
Gate open	V_{DROM}	100	200	400	600	V
On-state current:						
T_C = 75°C, conduction angle = 180°						
RMS	$I_{T(RMS)}$	4.5				A
Average	$I_{T(AV)}$	3.3				A
For other conditions		See Fig.3				
Peak surge (non-repetitive) on-state current:	I_{TSM}					
For one cycle of applied principal voltage						
50-Hz, sinusoidal		170				A
60-Hz, sinusoidal		200				A
For more than one full cycle of applied principal voltage		See Fig.4				
Rate of change of on-state current						
$V_D = V_{DROM}$, I_{GT} = 200 mA, t_r = 0.5 μs (See Fig.12)	di/dt	200				A/μs
Fusing current (for SCR protection):						
T_J = −40 to 100°C, t = 1.5 to 10 ms	I^2t	150				A^2s
Gate power dissipation:●						
Peak forward (for 1 μs max.)	P_{GM}	40				W
Peak reverse	P_{RGM}	See Fig.8				
Average (averaging time = 10 ms, max.)	$P_{G(AV)}$	0.5				W
Temperature range:■						
Storage	T_{stg}	−40 to 150				°C
Operating (case)	T_C	−40 to 100				°C
Pin temperature (during soldering):	T_P					
For 10 s max. (pins and case)		225				°C

See footnote on next page.

Footnotes for preceding page —

▲ These values do not apply if there is a positive gate signal. Gate must be open or negatively biased.

● Any product of gate current and gate voltage which results in a gate power less than the maximum is permitted.

■ Temperature measurement point is shown on the DIMENSIONAL OUTLINE.

ELECTRICAL CHARACTERISTICS, At Maximum Ratings Unless Otherwise Specified and at Indicated Case Temperature (T_C)

CHARACTERISTIC	SYMBOL	LIMITS For All Types Min.	Typ.	Max.	UNITS
Peak Off-State Current: (Gate open, T_C = 100°C)					
Forward at $V_D = V_{DROM}$	I_{DOM}	–	0.2	3	mA
Reverse at $V_R = V_{RROM}$	I_{ROM}	–	0.1	2	mA
Instantaneous On-State Voltage: i_T = 100 A, T_C = 25°C, See Fig.5	v_T	–	2.5	3	V
DC Gate Trigger Voltage: V_D = 12 V (dc), R_L = 30 Ω, T_C = 25°C	V_{GT}	–	1.1	2	V
For other conditions			See Fig.10		
DC Gate Trigger Current: V_D = 12 V (dc), R_L = 30 Ω, T_C = 25°C	I_{GT}	–	8	15	mA
For other conditions			See Fig.9		
DC Holding Current: Gate open, initial principal current = 150 mA, T_C = 25°C	I_{HO}	–	9	20	mA
For other conditions			See Fig.6		
Gate-Controlled Turn-On Time: (Delay Time + Rise Time) $V_D = V_{DROM}$, I_{GT} = 200 mA, t_r = 0.1 μs, i_T = 30 A (peak), T_C = 25°C (See Fig.11)	t_{gt}	–	1.6	2.5	μs
Circuit-Commutated Turn-Off Time: $V_D = V_{DROM}$, i_T = 18 A, pulse duration = 50 μs, dv/dt = 20 V/μs, di/dt = –30 A/μs, I_{GT} = 200 mA, T_C = 75°C See Fig.14	t_q	–	20	40	μs
Critical Rate of Rise of Off-State Voltage: $V_D = V_{DROM}$, exponential voltage rise, gate open, T_C = 100°C, See Fig.15	dv/dt	10	100	–	V/μs
Thermal Resistance: Steady-state					
Junction-to-case	$R_{\theta JC}$	–	–	5	°C/W
Junction-to-ambient	$R_{\theta JA}$	–	–	40	°C/W

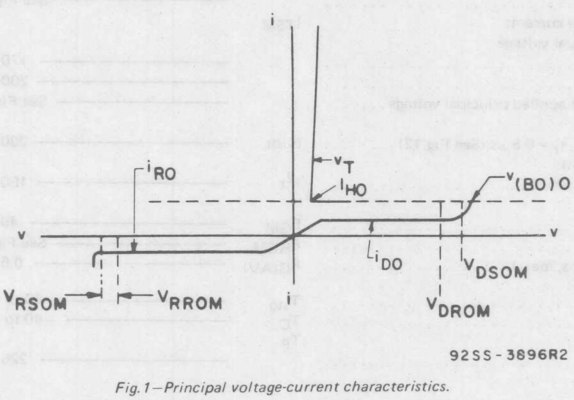


Fig.1—Principal voltage-current characteristics.

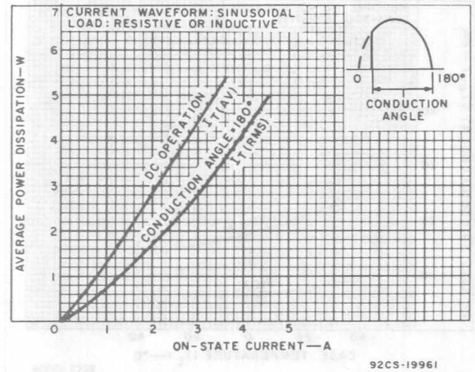


Fig.2—Power dissipation vs. on-state current.

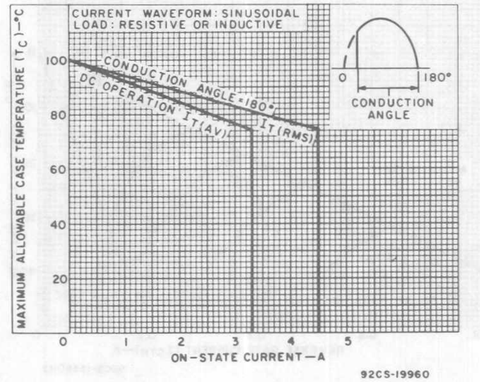


Fig.3—Maximum allowable case temperature vs. on-state current.

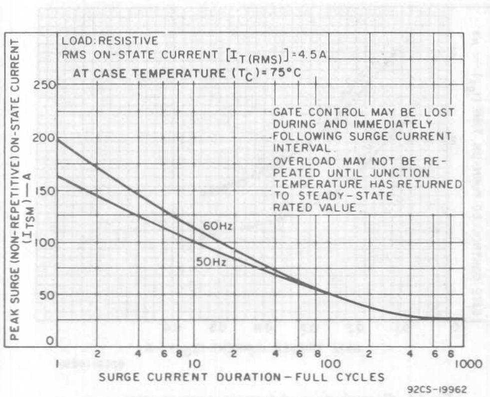


Fig.4—Peak surge on-state current vs. surge current duration.

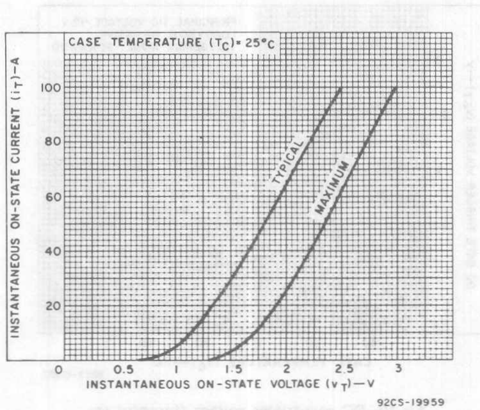


Fig.5—Instantaneous on-state current vs. on-state voltage.

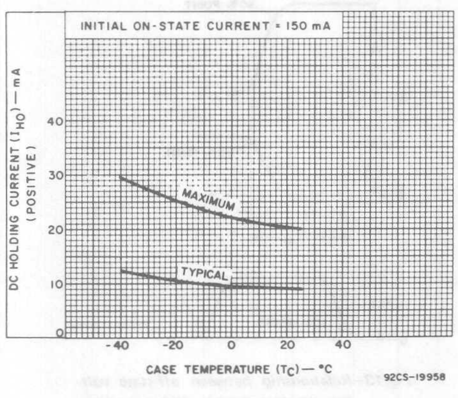


Fig.6—DC holding current vs. case temperature.

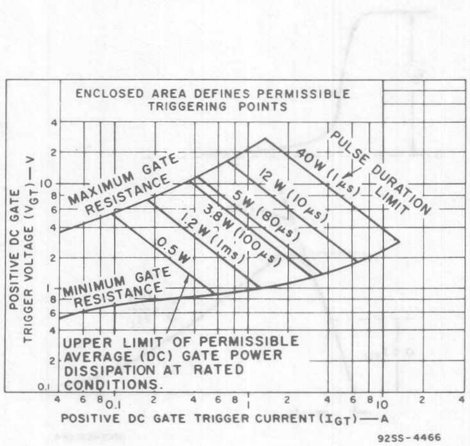


Fig.7—Gate pulse characteristics for forward triggering mode.

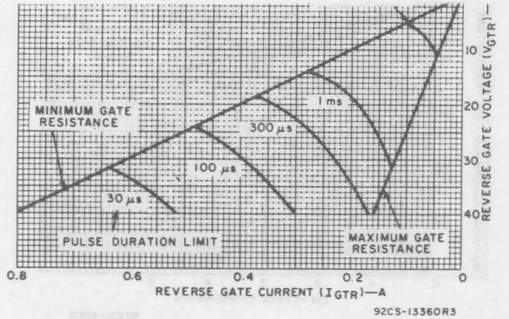


Fig.8—Reverse gate voltage vs. reverse gate current.

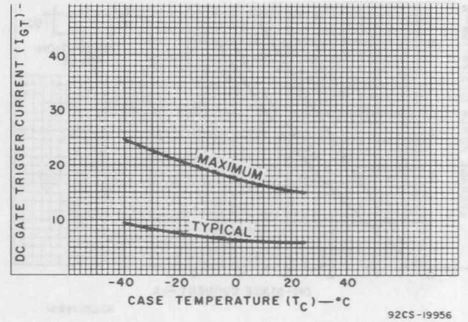


Fig.9—DC gate-trigger current (forward) vs. case temperature.

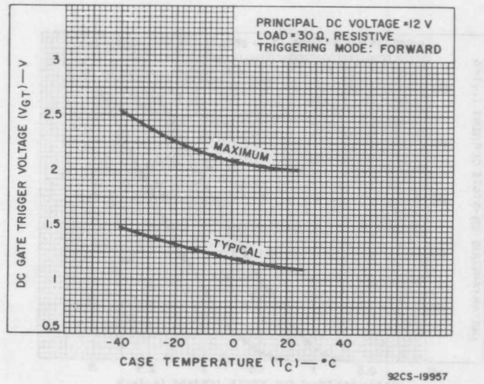


Fig.10—DC gate-trigger voltage (forward) vs. case temperature.

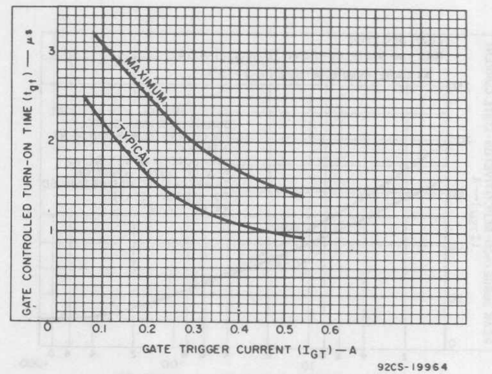


Fig.11—Gate-controlled turn-on time vs. gate-trigger current.

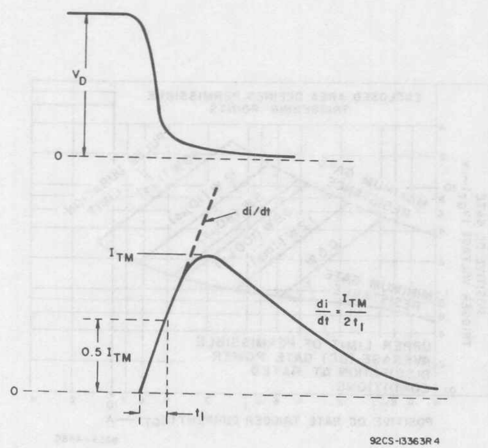


Fig.12—Rate of change of on-state current with time (defining di/dt).

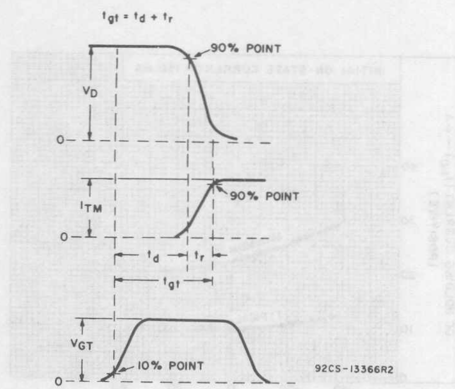


Fig.13—Relationship between off-state voltage, on-state current, and gate-trigger voltage showing reference points for definition of turn-on time (t_{gt}).

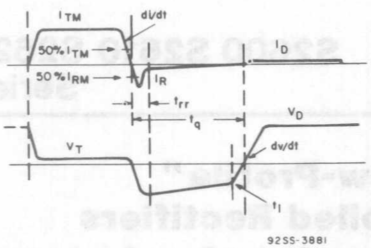


Fig.14—Relationship between instantaneous on-state current and voltage showing reference points for definition of circuit-commutated turn-off time (t_q).

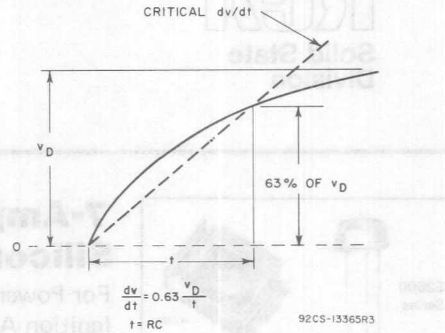
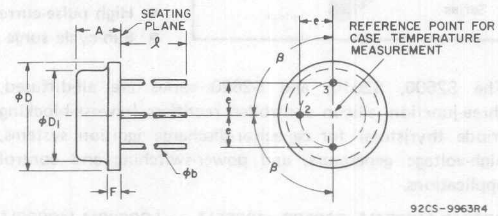


Fig.15—Rate of rise of off-state voltage with time (defining critical dv/dt).

DIMENSIONAL OUTLINE FOR TYPES S2400 SERIES JEDEC TO-8

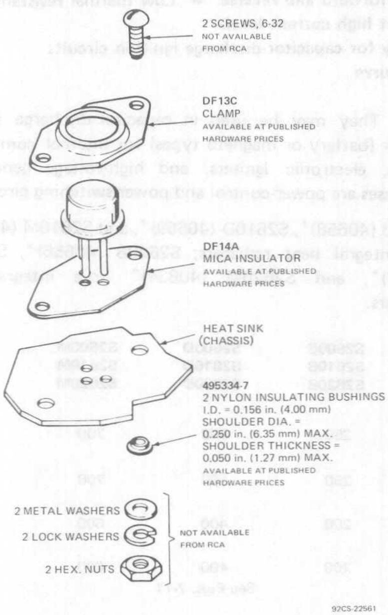


SYMBOL	INCHES MIN.	INCHES MAX.	MILLIMETERS MIN.	MILLIMETERS MAX.	NOTES
A	0.270	0.330	6.86	8.38	
φb	0.027	0.033	0.686	0.838	1
φD	0.550	0.650	13.97	16.51	–
φD1	0.444	0.524	11.28	13.31	–
e	0.136	0.146	3.45	3.71	–
F	–	0.115	–	2.92	–
ℓ	0.360	0.440	9.14	11.18	1
β	90° NOMINAL				

NOTE:
1. THREE LEADS.

TERMINAL CONNECTIONS

Pin 1 – Cathode
Pin 2 – Gate
Case, Pin 3 – Anode



In the United Kingdom, Europe, Middle East, and Africa, mounting-hardware policies may differ; check the availability of all items shown with your RCA sales representative or supplier.

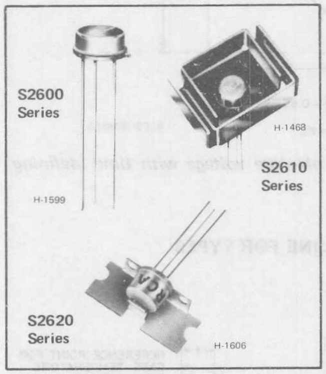
Fig.16—Suggested mounting arrangement.

RCA

Solid State
Division

Thyristors

S2600 S2610 S2620 Series



7-Ampere "Low-Profile" Silicon Controlled Rectifiers

For Power Switching, Power Control, Power Crowbar, and Ignition Applications

Features:

- **Forward and reverse gate ratings**
- **All-diffused center gate construction**
- **Low leakage currents, both forward and reverse**
- **Low forward voltage drop at high current levels**
- **High pulse-current capability for capacitor-discharge ignition circuits**
- **Sub-cycle surge capability curve**
- **High dv/dt capability**
- **Low switching losses**
- **Low thermal resistance**

The S2600, S2610, and S2620 series are all-diffused, three-junction, silicon controlled rectifiers (reverse-blocking triode thyristors) for capacitor-discharge ignition systems, high-voltage generators, and power-switching and control applications.

S2600B (40654)*, S2600D (40655)*, and S2600M (40833)* have a three-lead low-profile package (similar to the JEDEC TO-5). They may be used in capacitor-discharge ignition systems (battery or magneto types) for internal combustion engines, electronic igniters, and high-voltage generators. Other uses are power-control and power-switching circuits.

S2610B (40658)*, S2610D (40659)*, and S2610M (40835)* have integral heat radiators; S2620B (40656)*, S2620D (40657)*, and S2620M (40834)* have integral heat spreaders.

*Numbers in parentheses (e.g. 40654) are former RCA type numbers.

MAXIMUM RATINGS, *Absolute-Maximum Values:*
For Operation with Sinusoidal Supply Voltage at Frequencies up to 50/60 Hz and with Resistive or Inductive Load.

		S2600B S2610B S2620B	S2600D S2610D S2620D	S2600M S2610M S2620M	
NON-REPETITIVE PEAK REVERSE VOLTAGE•					
Gate open	V_{RSOM}	250	500	700	V
NON-REPETITIVE PEAK FORWARD VOLTAGE•					
Gate open	V_{DSOM}	250	500	700	V
REPETITIVE PEAK REVERSE VOLTAGE•					
Gate open	V_{RROM}	200	400	600	V
REPETITIVE PEAK OFF-STATE VOLTAGE•					
Gate open	V_{DROM}	200	400	600	V
RMS ON-STATE CURRENT (Conduction angle = 180°)	$I_{T(RMS)}$		See Figs. 7-11		
PEAK SURGE (NON-REPETITIVE) ON-STATE CURRENT:	I_{TSM}				
For one cycle of applied principal voltage					
60 Hz (sinusoidal)		100	100	100	A
50 Hz (sinusoidal)		85	85	85	A
For more than one cycle of applied principal voltage			See Fig. 12		
PEAK REPETITIVE ON-STATE CURRENT† (See Fig. 21):	I_{TRM}				
Duty factor = 0.1%, T_C = 75°C					
Pulse duration = 5 μs (min.), 20 μs (max.)		100	100	100	A
RATE OF CHANGE OF ON-STATE CURRENT:					
$V_{DM} = V_{DROM}$, I_{GT} = 200 mA, t_r = 0.5 μs (See Fig. 1)	di/dt		200		A/μs

Continued on next page.

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MAXIMUM RATINGS, (Cont'd).

For Operation with Sinusoidal Supply Voltage at Frequencies up to 50/60 Hz and with Resistive or Inductive Load.

		S2600B S2610B S2620B	S2600D S2610D S2620D	S2600M S2610M S2620M	
NON-REPETITIVE SUB-CYCLE SURGE CURRENT:					
T_C = 25°C, single pulse, I_{GT} = 50 mA, 10 μs square pulse			See Fig. 20		
GATE POWER DISSIPATION[▲]:					
PEAK FORWARD (for 1 μs max.)	P_{GM}	40	40	40	W
PEAK REVERSE	P_{RGM}		See Fig. 14		
AVERAGE (averaging time = 10 ms, max.)	$P_{G(AV)}$	0.5	0.5	0.5	W
TEMPERATURE RANGE[♦]:					
Storage	T_{stg}		-65 to +150		°C
Operating (case)	T_C		-65 to +100		°C
LEAD TEMPERATURE (During soldering)[■]:					
For 10 s max. for case or leads			225		°C

† When rms current exceeds 4 amperes (maximum rating for the anode lead), connection must be made to the case.

• These values do not apply if there is a positive gate signal. Gate must be open, terminated, or have negative bias.

▲ Any values of peak gate current or peak gate voltage that yield the maximum gate power are permissible.

♦ For information on the reference point of temperature measurement, see dimensional outlines.

■ When these devices are soldered directly to the heat sink, a 60/40 solder should be used. Case heating time should be a minimum . . . sufficient to allow the solder to flow freely.

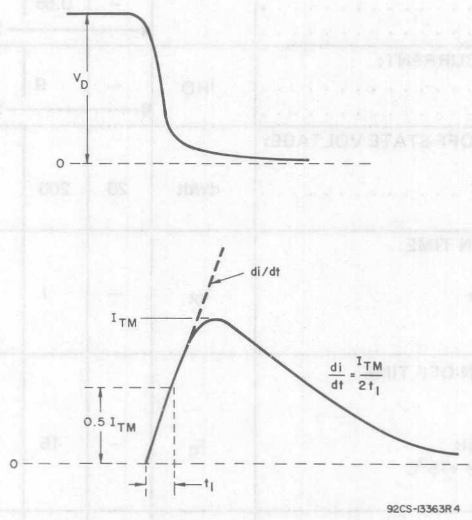


Fig. 1—Rate of change of on-state current with time (defining di/dt).

CHARACTERISTIC	SYMBOL	LIMITS S2600 Series MIN.	TYP.	MAX.	S2610 Series S2620 Series MIN.	TYP.	MAX.	UNITS
PEAK OFF-STATE CURRENT: (Gate Open, $T_C = +100^oC$)								
FORWARD, $V_D = V_{DROM}$	I_{DOM}	–	0.1	0.5	–	0.2	1.5	mA
REVERSE, $V_R = V_{RROM}$	I_{ROM}	–	0.05	0.5	–	0.1	1.5	
INSTANTANEOUS ON-STATE VOLTAGE: For i_T = 30 A and $T_C = +25^oC$	v_T	–	1.9	2.6	–	1.9	2.6	V
DC GATE TRIGGER CURRENT: V_D = 12 V (DC) R_L = 30 Ω $T_C = +25^oC$	I_{GT}	–	6	15	–	6	15	mA
For other case temperatures		See Fig. 16						
DC GATE TRIGGER VOLTAGE: V_D = 12 V (DC) R_L = 30 Ω $T_C = +25^oC$	V_{GT}	–	0.65	1.5	–	0.65	1.5	V
For other case temperatures		See Fig. 17						
INSTANTANEOUS HOLDING CURRENT: Gate Open and $T_C = +25^oC$	i_{HO}	–	9	20	–	9	20	mA
For other case temperatures		See Fig. 18						
CRITICAL RATE-OF-RISE OF OFF-STATE VOLTAGE: $V_D = V_{DROM}$ Exponential rise, $T_C = +100^oC$ (See Fig. 3)	dv/dt	20	200	–	20	200	–	V/μs
GATE CONTROLLED TURN-ON TIME: $V_D = V_{DROM}$, i_T = 4.5 A I_{GT} = 200 mA, 0.1 μs rise time $T_C = +25^oC$ (See Fig. 4)	t_{gt}	–	1	2	1	2	–	μs
CIRCUIT COMMUTATED TURN-OFF TIME: $V_D = V_{DROM}$, i_T = 2 A Pulse Duration = 50 μs dv/dt = 20V/μs, di/dt = -30A/μs I_{GT} = 200 mA at turn on, $T_C = +75^oC$ (See Fig. 5)	t_q	–	15	50	–	15	50	μs
THERMAL RESISTANCE: Junction-to-Case	$R_{\theta JC}$	–	–	5	–	–	5	°C/W
Junction-to-Ambient (See dimensional outlines)	$R_{\theta JA}$	–	–	120	–	–	30 (S2610 Series)	
Junction-to-Heat Spreader (See dimensional outline)	$R_{\theta JHS}$	–	–	–	–	–	7 (S2620 Series)	

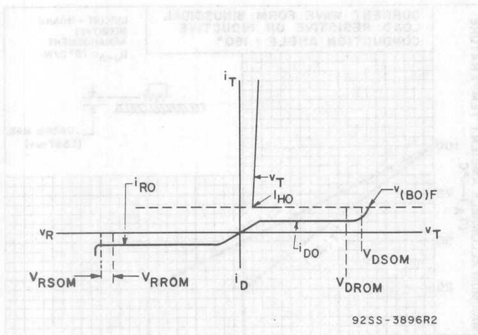


Fig. 2—Principal voltage-current characteristics.

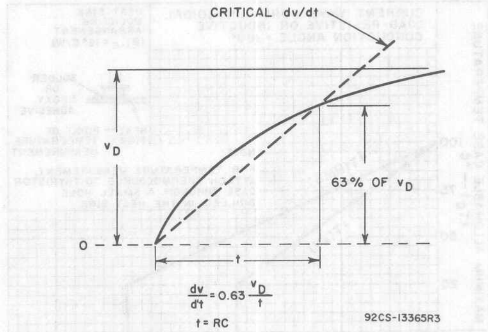


Fig. 3—Oscilloscope display of critical rate of rise of off-state voltage (critical dv/dt).

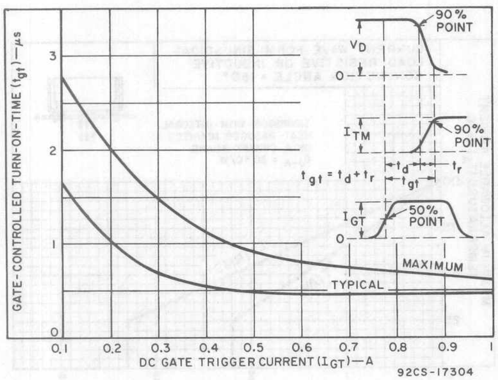


Fig. 4—Gate controlled turn-on time (t_{gt}) vs. gate trigger current.

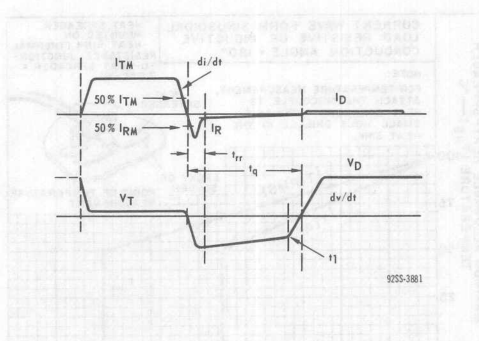


Fig. 5—Oscilloscope display for measurement of circuit commutated turn-off time (tq).

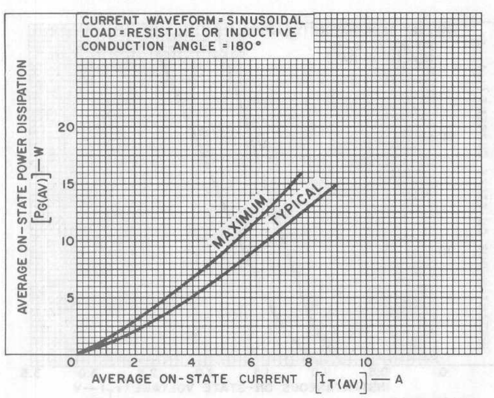


Fig. 6—Power dissipation vs. on-state current.

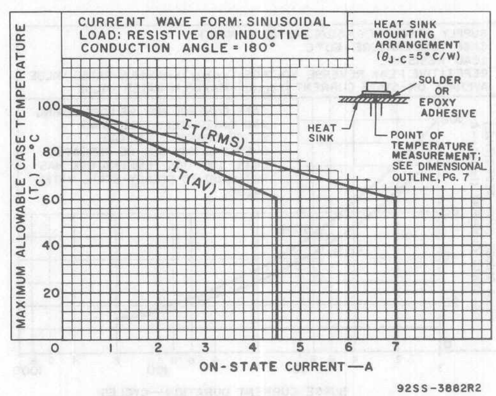


Fig. 7—Maximum allowable case temperature vs. on-state current for S2600 series.

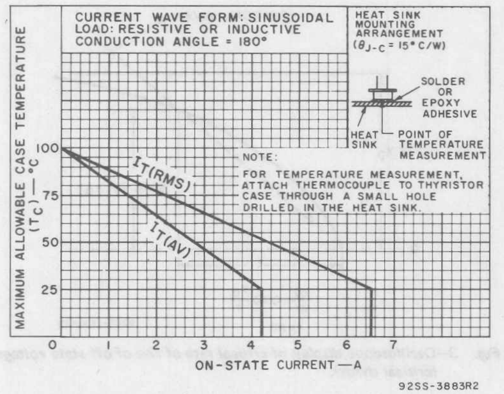


Fig. 8—Maximum allowable case temperature vs. on-state current for S2600 series.

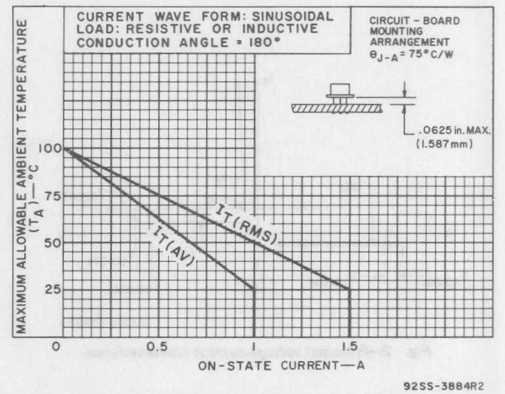


Fig. 9—Maximum allowable ambient temperature vs. on-state current for 2600 series.

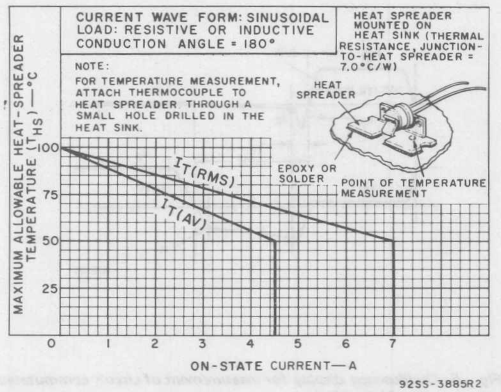


Fig. 10—Maximum allowable heat-speader temperature vs. on-state current for S2620 series.

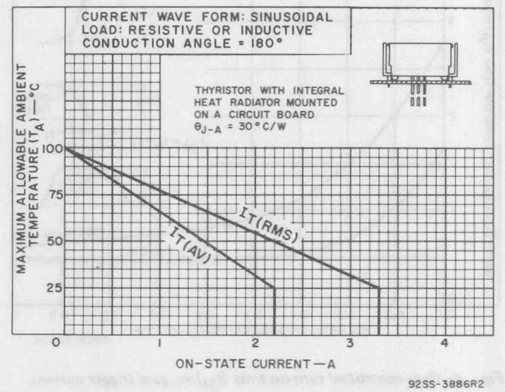


Fig. 11—Maximum allowable ambient temperature vs. on-state current for S2610 series.

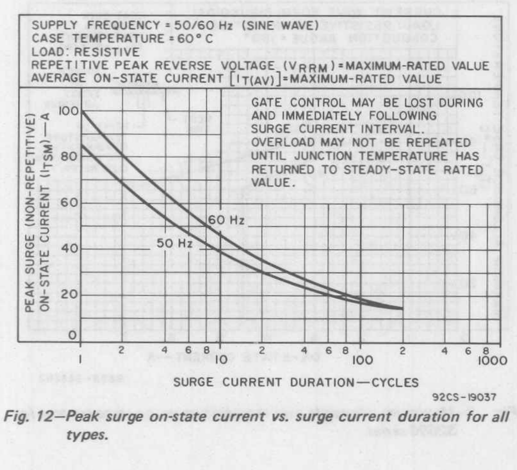


Fig. 12—Peak surge on-state current vs. surge current duration for all types.

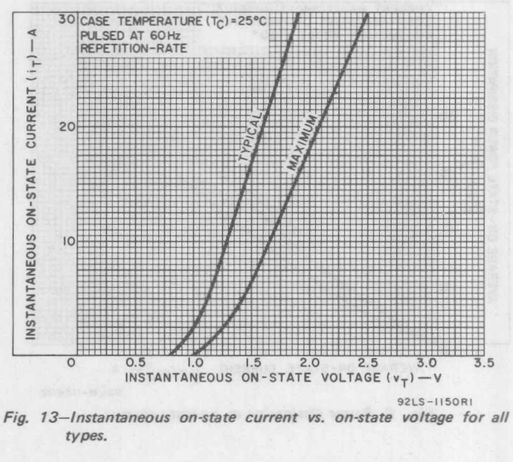


Fig. 13—Instantaneous on-state current vs. on-state voltage for all types.

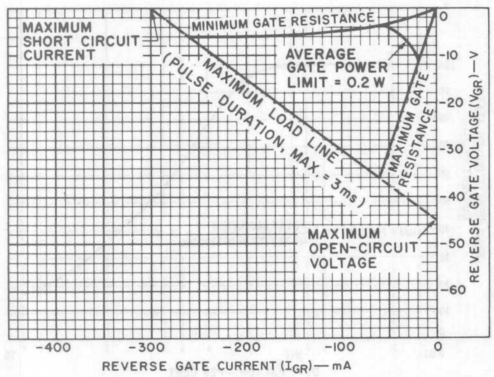


Fig. 14—Reverse gate voltage vs. reverse gate current.

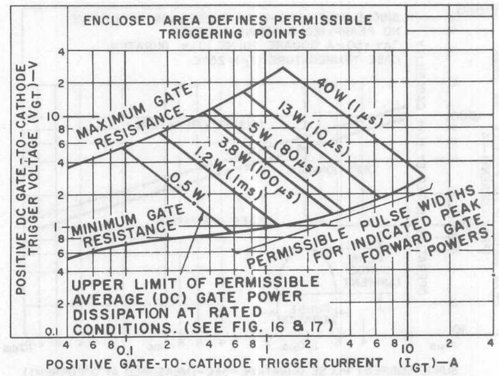


Fig. 15—Gate pulse characteristics for forward triggering mode.

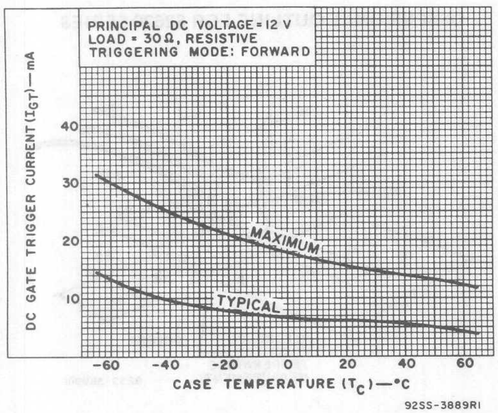


Fig. 16—DC gate-trigger current (forward) vs. case temperature.

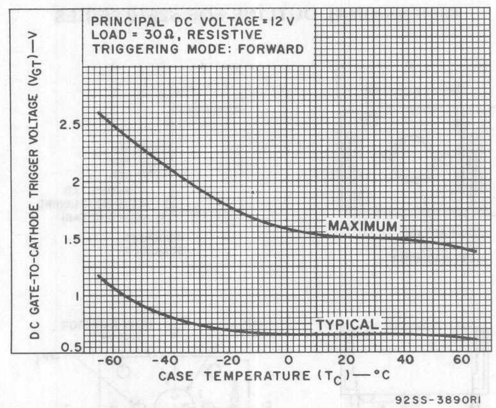


Fig. 17—DC gate-trigger voltage vs. case temperature.

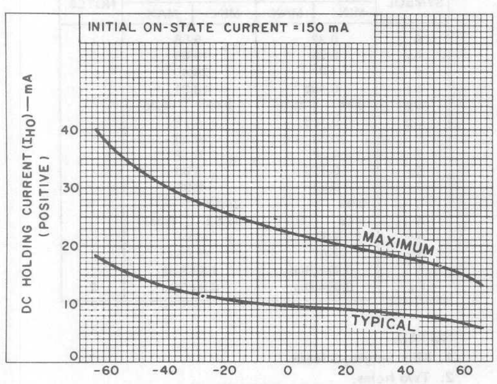


Fig. 18—DC holding current (positive) vs. case temperature.

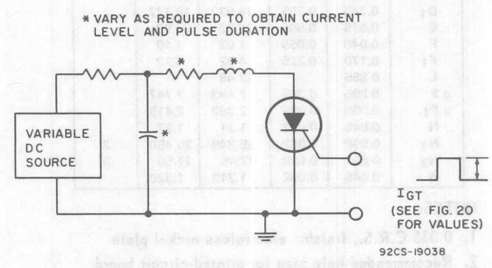


Fig. 19—Sub-cycle surge capability test circuit.

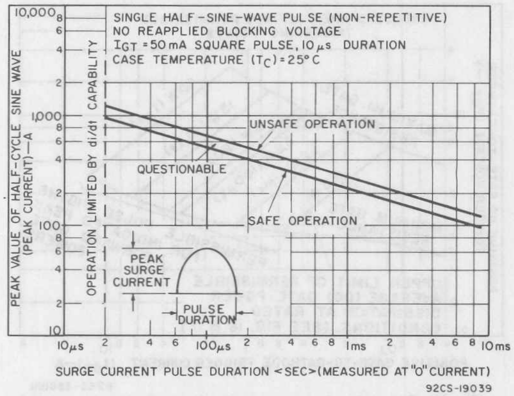


Fig. 20—Sub-cycle surge capability.

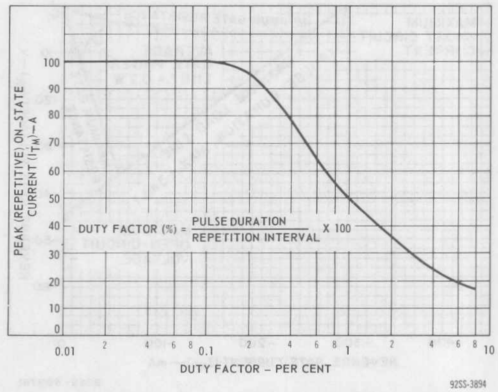
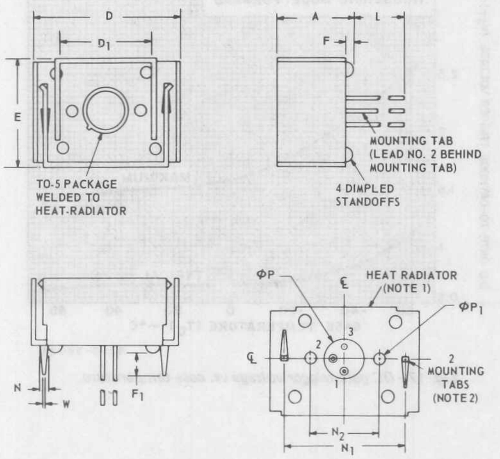


Fig. 21—Derating curve for peak pulse current (repetitive) vs. duty factor for the ignition circuit.

DIMENSIONAL OUTLINE FOR S2610 SERIES



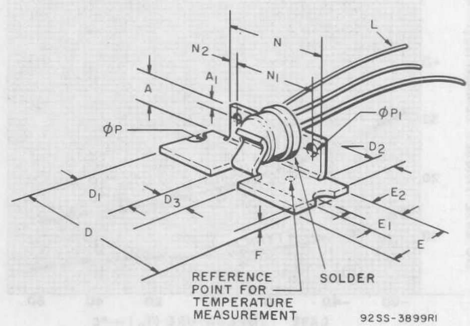
SYMBOL	INCHES		MILLIMETERS		NOTES
	MIN.	MAX.	MIN.	MAX.	
A	–	0.630	–	16.00	
D	1.205	1.235	30.61	31.37	
D_1	0.745	0.755	18.923	19.177	
E	0.875	0.905	22.22	22.99	
F	0.040	0.055	1.02	1.40	
F_1	0.170	0.225	4.32	5.72	
L	0.885	–	22.48	–	
ϕ P	0.295	0.305	7.493	7.747	
ϕ P_1	0.093	0.095	2.362	2.413	
N	0.048	0.062	1.21	1.57	
N_1	0.998	1.002	25.349	25.450	3
N_2	0.687	0.689	17.45	17.50	3
W	0.048	0.052	1.219	1.320	

NOTES:

1. 0.035 C.R.S., finish: electroless nickel plate
2. Recommended hole size for printed-circuit board is 0.070 in. (1.78 mm) dia.
3. Measured at bottom of heat radiator

92SS-3900R1

DIMENSIONAL OUTLINE FOR S2620 SERIES

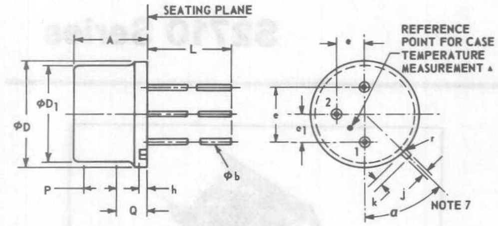


SYMBOL	INCHES		MILLIMETERS		NOTES
	MIN.	MAX.	MIN.	MAX.	
A	0.22		5.58		
A_1	0.75		19.05		
D	1.0		25.4		
D_1	0.406		10.31		
D_2	0.14	0.16	3.55	4.06	
D_3	0.188		4.77		
E	0.40		10.16		
E_1	0.32		8.12		
E_2	0.156		3.96		
F	0.02		0.05		
L	0.95	–	24.13	–	1
N	0.69	0.71	17.52	18.03	
N_1	0.55		13.97		
N_2	0.75		19.05		
ϕ P	0.072 Rad.		1.83 Rad.		
ϕ P_1	0.094 Dia.		2.39 Dia.		2

NOTES:

1. Min. length, 3 leads.
2. Two holes.

DIMENSIONAL OUTLINE FOR S2600 SERIES



SYMBOL	INCHES		MILLIMETERS		NOTES
	MIN.	MAX.	MIN.	MAX.	
A	0.160	0.180	4.06	4.57	
φb	0.017	0.021	0.432	0.533	2
φD	0.355	0.366	9.017	9.296	
φD_1	0.323	0.335	8.204	8.51	
e	0.190	0.210	4.83	5.33	
e_1	0.100 TRUE POSITION		2.54 TRUE POSITION		4, 5
he	0.15	0.035	0.381	0.889	
j	0.028	0.035	0.711	0.889	5
k	0.029	0.045	0.737	1.14	3, 5
L	0.985	1.015	25.02	25.78	2
P	0.100		2.54		1
Q					6
r		0.007		0.179	
α	42°	48°			5, 7

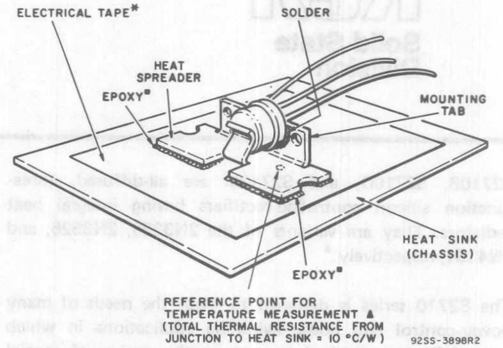
92SS 3901R1

NOTES:

1. This zone is controlled for automatic handling. The variation in actual diameter within the zone shall not exceed 0.012 in. (0.279mm).
2. (Three Leads) φb applies between seating plane and 1.015in. (25.78mm).
3. Measured from maximum diameter of the actual device.
4. Leads having maximum diameter 0.021in. (0.533mm) measured at the seating plane of the device shall be within 0.007in. (0.178mm) of their true positions relative to the maximum-width tab.
5. The device may be measured by direct methods or by the gage and gaging procedure described on gage drawing GS-1 of JEDEC publication 12E, May 1964.
6. Details of outline in this zone optional.
7. Tab centerline.

▲CASE TEMPERATURE MEASUREMENT

The specified temperature-reference point should be used when making temperature measurements. A low-mass temperature probe or thermocouple having wire no larger than AWG No. 26 should be attached at the temperature reference point.



* Scotch brand electrical tape No. 27 (thermo setting one side), Minnesota Mining & Mfg. Co., St Paul, Minnesota, or equivalent.

■ An epoxy such as Hysol Epoxy Patch Kit 6C, Hysol Corporation, Olean, N.Y. 14761, or equivalent.

▲For heat-sink temperature measurement, the thermocouple (wire no larger than AWG No. 26) should be inserted in a small, shallow hole drilled in (but not through) the heat sink at the indicated temperature reference point.

Fig. 22–Suggested mounting arrangement for S2620 series (case insulated from heat sink).

TERMINAL CONNECTIONS

S2600 SERIES

Lead 1 – Cathode
Lead 2 – Gate
Case, Lead 3 – Anode

S2610 SERIES

Lead 1 – Cathode
Lead 2 – Gate
Case, Heat Radiator – Anode

S2620 SERIES

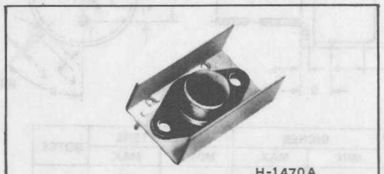
Lead 1 – Cathode
Lead 2 – Gate
Case, Heat Spreader – Anode

S2710B, S2710D, and S2710M are all-diffused, three-junction silicon controlled-rectifiers having integral heat radiators. They are variants of the 2N3228, 2N3525, and 2N4101, respectively.*

The S2710 series is designed to meet the needs of many power-control and power-switching applications in which heat sinks are required but where the design of special cooling systems to achieve the full current rating of the thyristor is not warranted.

The radiator design of these devices has tabs to allow printed-circuit board mounting and holes to allow chassis mounting if desired.

* Ratings and characteristics given for the 2N3228, 2N3225, and 2N4101 in RCA data bulletin File No. 114 are also applicable to the devices in the S2710 series.



H-1470A

Thyristor with Heat Radiator	Thyristor without Heat Radiator
S2710B (40504)	2N3228
S2710D (40505)	2N3525
S2710M (40506)	2N4101

Numbers in parentheses (e.g. 40504) are former RCA type numbers.

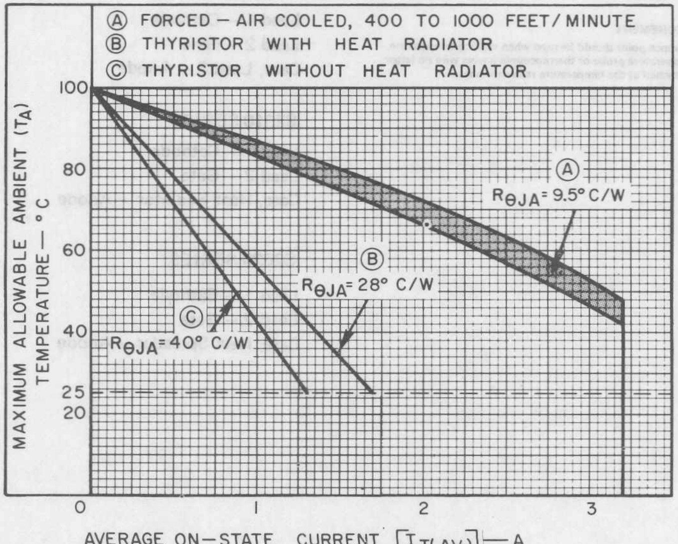
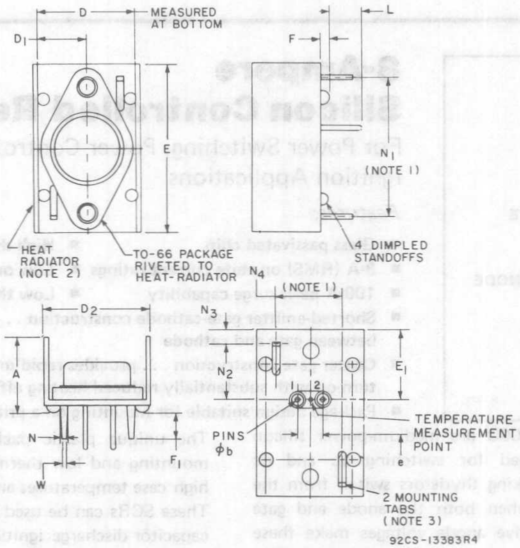


Fig. 1 – Maximum allowable ambient temperature vs. on-state current.

DIMENSIONAL OUTLINE
JEDEC TO-66 WITH HEAT RADIATOR



SYMBOL	INCHES MIN.	INCHES MAX.	MILLIMETERS MIN.	MILLIMETERS MAX.	NOTES
A	–	0.620	–	15.75	
φb	0.028	0.034	0.711	0.864	
D	0.750	0.760	19.05	19.30	
D_1	0.370	0.385	9.40	9.78	
D_2	0.820	0.920	20.83	23.37	
E	1.297	1.327	32.94	33.70	
E_1	0.546	0.566	13.87	14.37	
e	0.190	0.210	4.83	5.33	
F	0.30	0.55	7.62	13.97	
F_1	0.175	0.210	4.44	5.33	
L	0.270	–	6.86	–	
N	0.052	0.065	1.32	1.65	
N_1	1.098	1.102	27.89	27.99	1
N_2	0.448	0.452	11.38	11.47	
N_3	0.099	0.113	0.25	0.29	
N_4	0.498	0.502	12.65	12.75	
W	0.048	0.060	1.22	1.52	

NOTES:
1. Measured at bottom of heat radiator.
2. 0.035 in. (0.889) C.R.S., tin plated.
3. Recommended hole size for printed-circuit board is 0.070 in. (1.778) dia.

TERMINAL CONNECTIONS

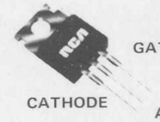
Pin 1: Gate
Pin 2: Cathode
Radiator, Case: Anode

RCA

Solid State Division

Thyristors

S2800 Series



8-Ampere Silicon Controlled Rectifiers

For Power Switching, Power Control, and Ignition Applications

Features:

- Glass passivated chip
- 8-A (RMS) on-state current ratings
- 100-A peak surge capability
- High dv/dt capability
- Low on-state voltage at high current levels
- Low thermal resistance
- Shorted-emitter gate-cathode construction . . . contains an internally diffused resistor between gate and cathode
- Center gate construction . . . provides rapid uniform gate-current spreading for faster turn-on with substantially reduced heating effects
- Package design suitable for mounting on a printed-circuit board

S2800A, S2800B, and S2800D are medium-power silicon controlled rectifiers designed for switching ac and dc currents. These reverse-blocking thyristors switch from the off-state to the on-state when both the anode and gate voltages are positive. Negative anode voltages make these devices revert to the blocking state regardless of gate-voltage polarity.

The unique plastic package design provides easy package mounting and low thermal resistance, allowing operation at high case temperatures and permitting reduced heat-sink size. These SCRs can be used in lighting and motor-speed control, capacitor-discharge ignition circuits, high-voltage generators, automotive applications, and power-switching systems.

MAXIMUM RATINGS, *Absolute-Maximum Values:*

		S2800A (40867)●	S2800B (40868)●	S2800D (40869)●	
NON-REPETITIVE PEAK REVERSE VOLTAGE*					
Gate Open	V_{RSOM}	125	250	500	V
NON-REPETITIVE PEAK FORWARD VOLTAGE*					
Gate Open	V_{DSOM}	125	250	500	V
REPETITIVE PEAK REVERSE VOLTAGE*					
Gate Open	V_{RROM}	100	200	400	V
REPETITIVE PEAK OFF-STATE VOLTAGE*					
Gate Open	V_{DROM}	100	200	400	V
RMS ON-STATE CURRENT					
For T_C of +80°C and Conduction Angle of 180°	$I_{T(RMS)}$	8	8	8	A
PEAK SURGE (NON-REPETITIVE) ON-STATE CURRENT:	I_{TSM}				
For one cycle of 400-Hz applied principal voltage		200	200	200	A
For one cycle of 60-Hz applied principal voltage		100	100	100	A
For one cycle of 50-Hz applied principal voltage		85	85	85	A
For more than one full cycle of applied principal voltage			See Fig. 7.		
RATE OF CHANGE OF ON-STATE CURRENT					
$V_D = V_{DROM}$, I_{GT} = 80 mA, t_r = 0.5 μs (See Fig. 3)	di/dt	100	100	100	A/μs
GATE POWER DISSIPATION▲:					
PEAK FORWARD (for 10 μs max.)	P_{GM}	16	16	16	W
PEAK REVERSE	P_{RGM}		See Fig. 13.		
AVERAGE (averaging time = 10 ms max.)	$P_{G(AV)}$	0.5	0.5	0.5	W
TEMPERATURE RANGE♣:					
Storage			-65 to +150		°C
Operating (Case)			-65 to +100		°C
Soldering (10 sec. max.)			250		°C

*These values do not apply if there is a positive gate signal. Gate must be open or negatively biased.

▲Any values of peak gate current or peak gate voltage which result in an equal or lower power are permissible.

♣For information on the reference point of temperature measurement, see Dimensional Outline.

● Numbers in parentheses (e.g. 40867) are former RCA type numbers.

ELECTRICAL CHARACTERISTICS, *At Maximum Ratings and at Indicated Case Temperature (T_C) Unless Otherwise Specified.*

CHARACTERISTIC	SYMBOL	LIMITS									UNITS
		S2800A			S2800B			S2800D			
		MIN.	TYP.	MAX.	MIN.	TYP.	MAX.	MIN.	TYP.	MAX.	
PEAK OFF-STATE CURRENT: (Gate Open, T_C = +100°C) FORWARD, $V_D = V_{DROM}$	I_{DOM}	–	0.1	2	–	0.1	2	–	0.1	2	mA
REVERSE (REPETITIVE), $V_R = V_{RROM}$	I_{ROM}	–	0.1	3	–	0.1	3	–	0.1	3	mA
INSTANTANEOUS ON-STATE VOLTAGE: For i_T = 30 A and T_C = +25°C	v_T	–	1.7	2.0	–	1.7	2.0	–	1.7	2.0	V
DC GATE TRIGGER CURRENT: V_D = 12 V (DC) R_L = 30 Ω T_C = +25°C	I_{GT}	–	8	15	–	8	15	–	8	15	mA
For other case temperatures						See Fig. 9.					
DC GATE TRIGGER VOLTAGE: V_D = 12 V (DC) R_L = 30 Ω T_C = +25°C	V_{GT}	–	0.9	1.5	–	0.9	1.5	–	0.9	1.5	V
For other case temperatures						See Fig. 10.					
INSTANTANEOUS HOLDING CURRENT: Gate Open and T_C = +25°C	i_{HO}	–	10	20	–	10	20	–	10	20	mA
For other case temperatures						See Fig. 11.					
CRITICAL RATE-OF-RISE OF OFF-STATE VOLTAGE: $V_D = V_{DROM}$ Exponential rise, T_C = +100°C (See Fig. 2.)	dv/dt	75	300	–	50	300	–	30	200	–	V/μs
For other case temperatures						See Fig. 14.					
GATE CONTROLLED TURN-ON TIME: $V_D = V_{DROM}$, i_T = 4.5 A, i_T = 2 A I_{GT} = 80 mA, 0.1 μs rise time T_C = +25°C (See Fig. 5.)	t_{gt}	–	1.6	2.5	–	1.6	2.5	–	1.6	2.5	μs
CIRCUIT COMMUTATED TURN-OFF TIME: $V_D = V_{DROM}$, i_T = 2 A Pulse Duration = 50 μs dv/dt = 200 V/μs, di/dt = –10 A/μs I_{GT} = 200 mA at turn on, T_C = +75°C (See Fig. 4.)	t_q	–	10	35	–	10	35	–	10	35	μs
THERMAL RESISTANCE: Junction-to-Case	$R_{\theta J\text{-}C}$	–	–	2.2	–	–	2.2	–	–	2.2	°C/W
Junction-to-Ambient	$R_{\theta J\text{-}A}$	–	–	60	–	–	60	–	–	60	°C/W

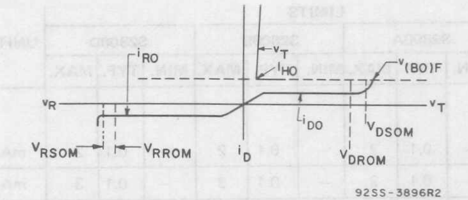


Fig. 1—Principal voltage-current characteristic.

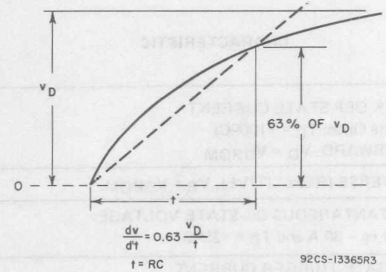


Fig. 2—Rate of rise of off-state voltage with time (defining critical dv/dt).

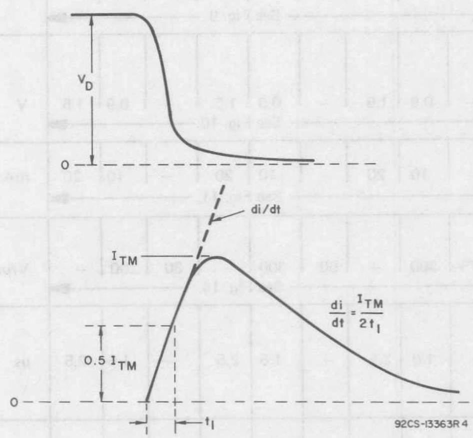


Fig. 3—Rate of change of on-state current with time (defining di/dt).

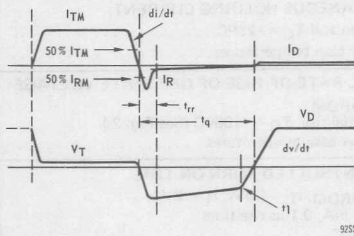


Fig. 4—Relationship between instantaneous on-state current and voltage, showing reference points for definition of circuit-commutated turn-off time (t_q).

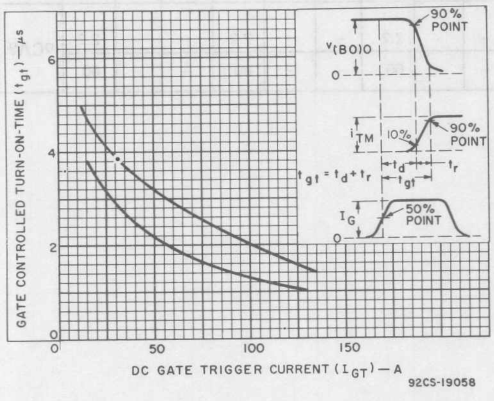


Fig. 5—Typical gate-controlled turn-on time vs. gate trigger current.

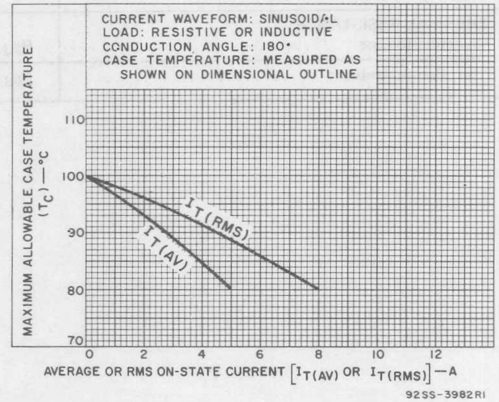


Fig. 6—Maximum allowable case temperature vs. on-state current.

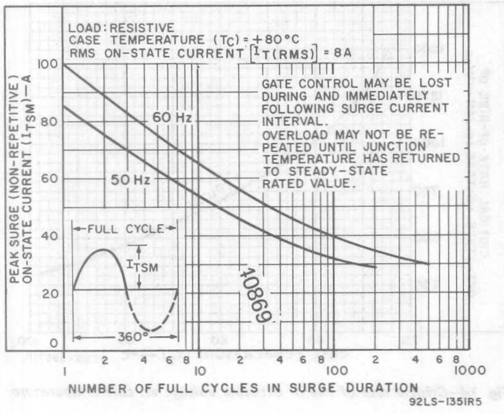


Fig. 7—Allowable peak surge on-state current vs. surge duration.

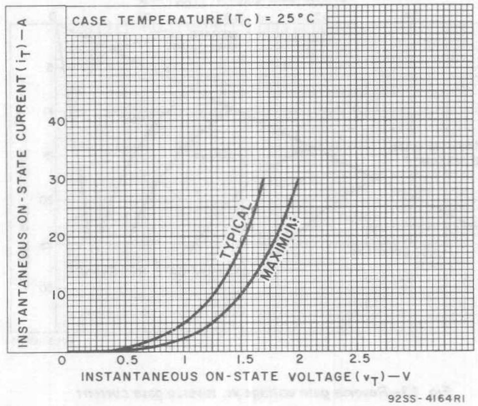


Fig. 8—Instantaneous on-state current vs. on-state voltage.

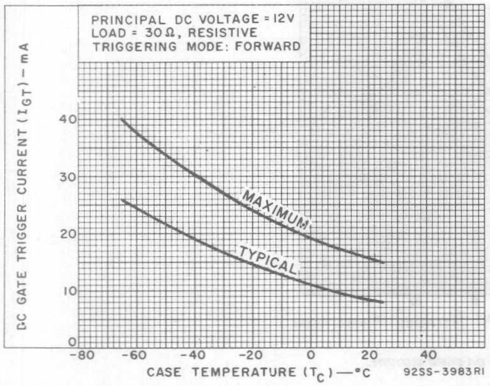


Fig. 9—DC gate-trigger current (forward) vs. case temperature.

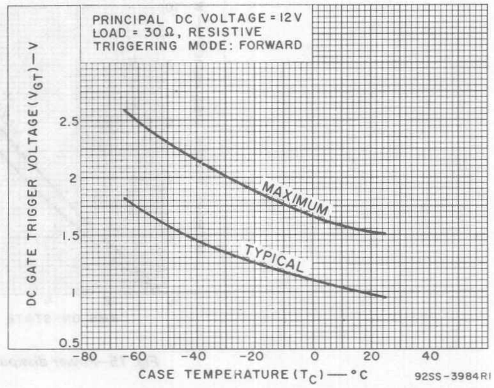


Fig. 10—DC gate-trigger voltage (forward) vs. case temperature.

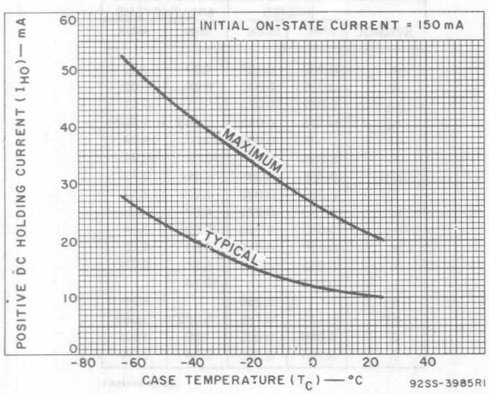


Fig. 11—Holding current (positive) vs. case temperature.

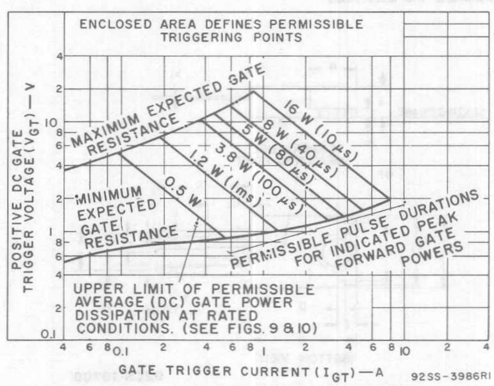


Fig. 12—Typical forward-biased gate characteristics.

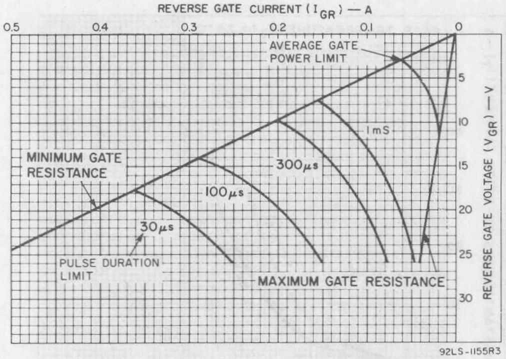


Fig. 13—Reverse gate voltage vs. reverse gate current.

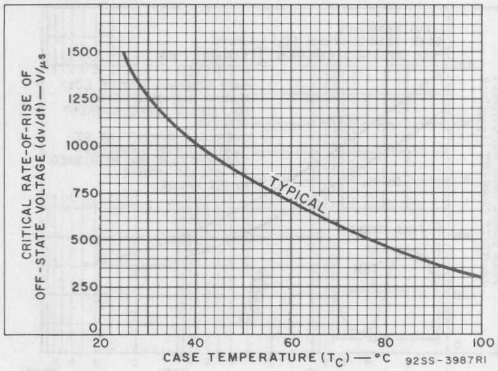


Fig. 14—Critical rate of rise of off-state voltage vs. case temperature.

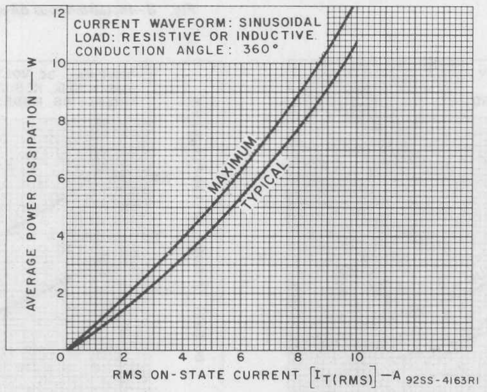
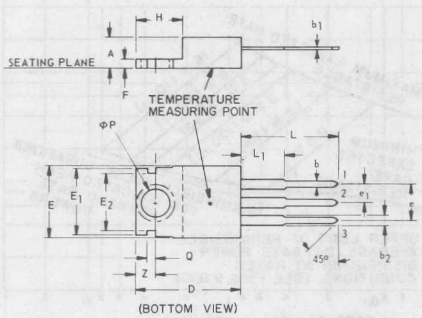


Fig. 15—Power dissipation vs. on-state current.

DIMENSIONAL OUTLINE (JEDEC TO-220 AB)

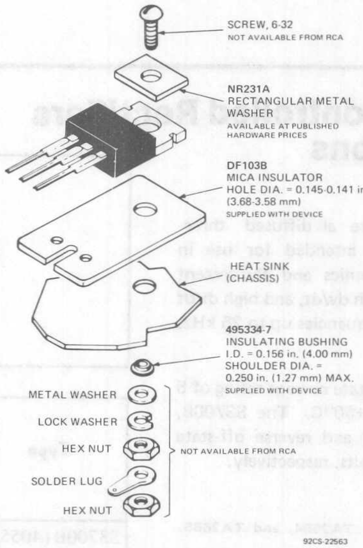


SYMBOL	INCHES MIN.	INCHES MAX.	MILLIMETERS MIN.	MILLIMETERS MAX.
A	0.160	0.190	4.07	4.82
b	0.025	0.040	0.64	1.02
b_1	0.012	0.020	0.31	0.51
b_2	0.045	0.055	1.143	1.397
D	0.575	0.600	14.61	15.24
E	0.395	0.410	10.04	10.41
E_1	0.365	0.385	9.28	9.77
E_2	0.300	0.320	7.62	8.12
e	0.180	0.220	4.57	5.58
e_1	0.080	0.120	2.03	3.04
F	0.020	0.055	0.51	1.39
H	0.235	0.265	5.97	6.73
L	0.500		12.70	
L_1		0.250		6.35
ϕP	0.141	0.145	3.582	3.683
Q	0.040	0.060	1.02	1.52
Z	0.100	0.120	2.54	3.04

92CM-15015R1

TERMINAL CONNECTIONS

No. 1 — Cathode
Mounting Flange, No. 2 — Anode
No. 3 — Gate



In the United Kingdom, Europe, Middle East, and Africa, mounting-hardware policies may differ; check the availability of all items shown with your RCA sales representative or supplier.

Fig. 16—Suggested mounting hardware.

All-Diffused Silicon Controlled Rectifiers for Inverter Applications

JEDEC TO-66

S3700B, S3700D, and S3700M* are all-diffused three-junction silicon controlled rectifiers intended for use in inverter applications such as ultrasonics and fluorescent lighting. They feature fast turn-off, high dv/dt, and high di/dt characteristics, and may be used at frequencies up to 25 kHz.

Each of these devices has an rms on-state current rating of 5 amperes at a case temperature of +60°C. The S3700B, S3700D, and S3700M have forward and reverse off-state voltage ratings of 200, 400, and 600 volts, respectively.

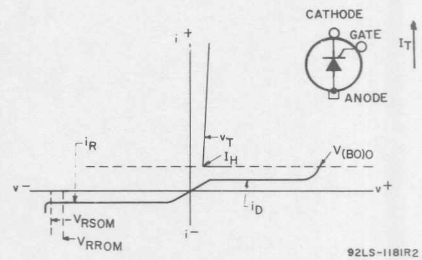
*Formerly Developmental Types TA2653, TA2654, and TA2655, respectively.

Type	Forward and Reverse Voltage V	$I_{T(RMS)}$ @ T_C = +60° C A
S3700B (40553)●	200	5
S3700D (40554)●	400	5
S3700M (40555)●	600	5

●Numbers in parentheses (e.g. 40553) are former RCA type numbers.

- RMS On-State Current – 5 Amperes at T_C = + 60° C
- Fast Turn-Off Time – 6 μs maximum
- High dv/dt Capability – 100 V/μs minimum
- High di/dt Capability – 200 A/μs
- Shorted-Emitter and Center-Gate Design – Removes restrictions on forward and reverse gate voltage and peak gate current

ANODE-TO-CATHODE VOLTAGE-CURRENT CHARACTERISTIC



Principal voltage is the voltage between the main terminals. Principal voltage is called positive, or forward, when the anode potential is higher than the cathode potential, and called negative when the anode potential is lower than the cathode potential.

Principal current is the current flowing between anode and cathode.

Absolute-Maximum Ratings, for Operation with Sinusoidal AC Supply Voltage At Low to Ultrasonic Frequencies, and with Resistive or Inductive Load

RATINGS	MAXIMUM VALUES			UNITS
	S3700B	S3700D	S3700M	
Non-Repetitive Peak Reverse Voltage, V_{RSOM}				
Gate Open	330	660	700	V
Repetitive Peak Reverse Voltage, V_{RROM}				
Gate Open	200	400	600	V
Repetitive Peak Off-State Voltage, V_{DROM}				
Gate Open	700	700	700	V
On-State Current:				
For case temperature of +60° C and 60 Hz				
Average DC value at a conduction angle of 180°, $I_{T(AV)}$	3.2	3.2	3.2	A
RMS value, $I_{T(RMS)}$	5	5	5	A
For other conditions		See *Fig.9*		
Peak Surge (Non-Repetitive) On-State Current, I_{TSM}				
For one cycle of applied voltage	80	80	80	A
For more than one cycle of applied voltage		See *Fig.11*		
Sub-Cycle for Fusing, I^2t				
For a period of 8.3 ms	25	25	25	A^2s
Critical Rate of Rise of On-State Current, Critical di/dt				
$V_{DX} = V_{(BO)O}$ rated value, I_{GT} = 50 mA, 0.1 μs rise time	200	200	200	A/μs
Gate Power Dissipation*				
Peak, Forward or Reverse, for 10 μs duration, P_{GM}	13	13	13	W
Average, $P_{G(AV)}$	0.5	0.5	0.5	W
Temperature:■				
Storage, T_{stg}	-40 to +150	-40 to +150	-40 to +150	°C
Operating (Case), T_C	-40 to +100	-40 to +100	-40 to +100	°C

*Any values of peak gate current or peak gate voltage to give the maximum gate power are permissible.

■For information on the reference point of temperature measurement, see *Dimensional Outline.*

Characteristics at Maximum Ratings (unless otherwise specified), and at Indicated Case Temperature (T_C)

CHARACTERISTICS	LIMITS									UNITS
	S3700B			S3700D			S3700M			
	Min.	*Typ.*	*Max.*	*Min.*	*Typ.*	*Max.*	*Min.*	*Typ.*	*Max.*	
Breakover Voltage, $V_{(BO)O}$ Gate Open At T_C = +100° C	200	–	–	400	–	–	600	–	–	V
Peak Off-State Current: Gate Open At T_C = +100° C										
Forward, I_{DOM} V_{DO} = $V_{(BO)O}$ rated value	–	0.5	3	–	0.5	3	–	0.5	3	mA
Reverse, I_{RROM} V_{RO} = V_{RROM}	–	0.3	1.5	–	0.3	1.5	–	0.3	1.5	mA
Instantaneous On-State Voltage, v_T For an on-state current of 30 A and T_C = +25° C (See *Fig.13)*	–	2.2	3	–	2.2	3	–	2.2	3	V
DC Gate Trigger Current, I_{GT} At T_C = +25° C (See *Fig.5)*	–	15	40	–	15	40	–	15	40	mA(dc)
DC Gate Trigger Voltage, V_{GT} At T_C = +25° C (See *Fig.5)*	–	1.8	3.5	–	1.8	3.5	–	1.8	3.5	V(dc)
Holding Current, I_H At T_C = +25° C	–	20	50	–	20	50	–	20	50	mA
Critical Rate of Rise of Off-State Voltage, Critical dv/dt V_{DO} = $V_{(BO)O}$ (rated value), linear rise, and T_C = +80° C (See waveshapes of *Fig.2)*	100	250	–	100	250	–	100	250	–	V/μs
Gate-Controlled Turn-On Time, t_{gt} (Delay Time + Rise Time) V_{DX} = $V_{(BO)O}$ rated value, I_{TM} = 2 A, I_{GT} = 300 mA, 0.1 μs rise time, and T_C = +25° C (See waveshapes of *Fig.3)*	–	0.7	–	–	0.7	–	–	0.7	–	μs
Circuit-Commutated Turn-Off Time, t_q (Reverse Recovery Time + Gate Recovery Time) V_{DX} = $V_{(BO)O}$ rated value, I_{TM} = 2 A, 50 μs min. pulse width, V_{RX} = 80 V min., rise time = 0.1 μs, dv/dt = 100 V/μs, di_R/dt = 10 A/μs, I_{GT} = 100 mA at turn-on, V_{GT} = 0 V at turn-off, and T_C = +80° C (See waveshapes of *Fig.4)*	–	4	6	–	4	6	–	4	6	μs

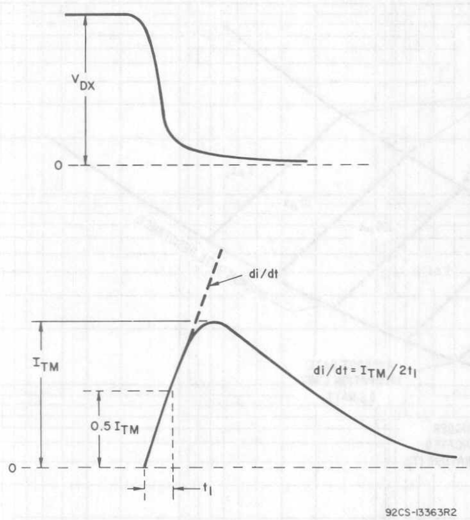


Fig. 1—Waveshape of di/dt rating test.

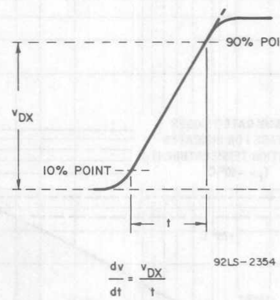


Fig. 2—Waveshape of critical dv/dt rating test (linear rise).

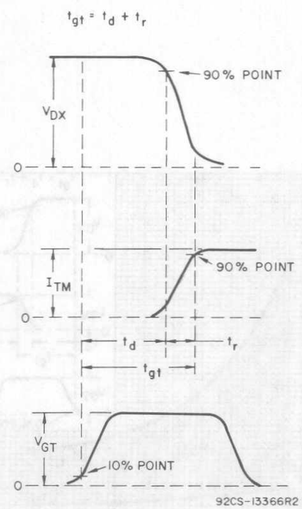


Fig. 3—Waveshape of t_{gt} rating test.

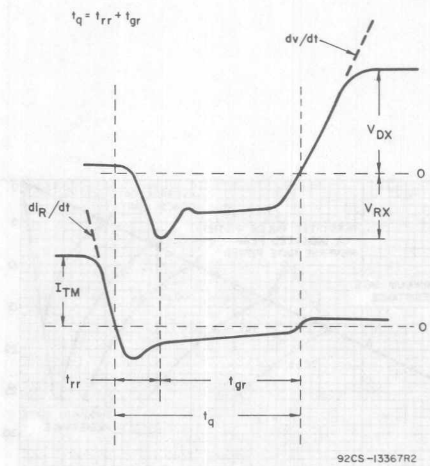


Fig. 4—Waveshape of t_q rating test.

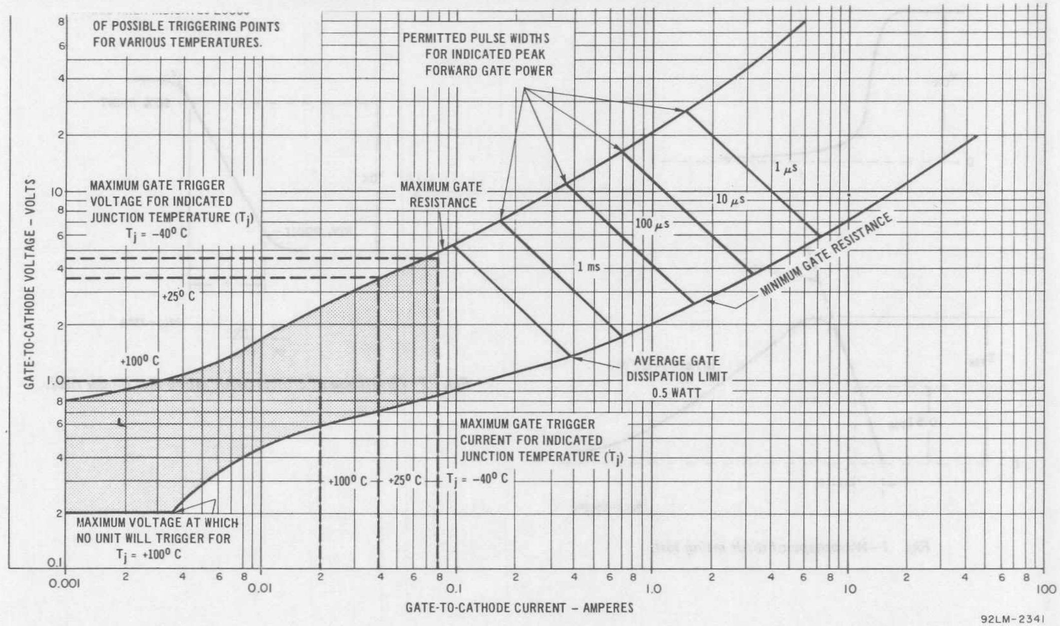


Fig. 5—Forward gate characteristics.

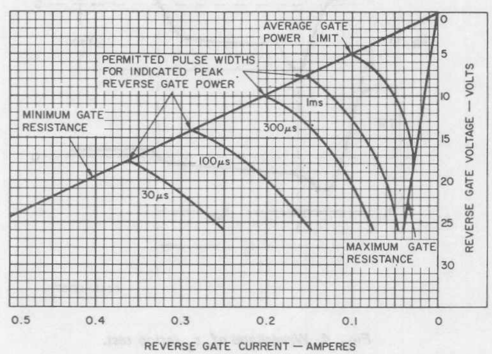


Fig. 6—Reverse gate characteristics.

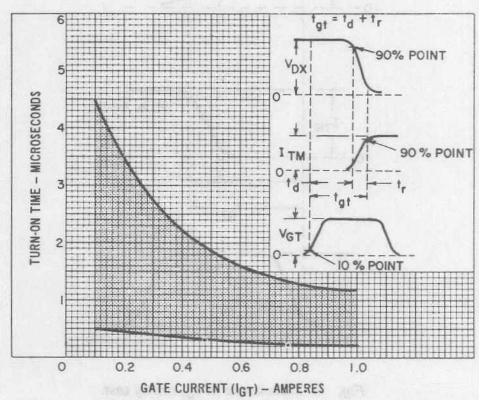


Fig. 7— Turn-on-time characteristics.

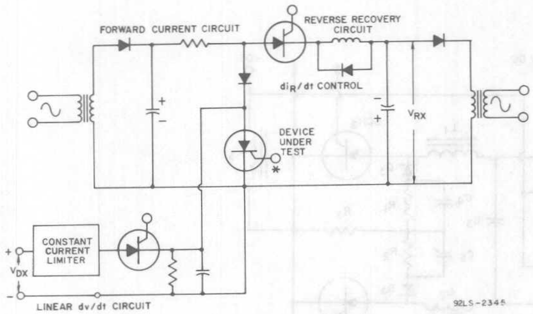


Fig. 8—Conventional turn-off-time test circuit.

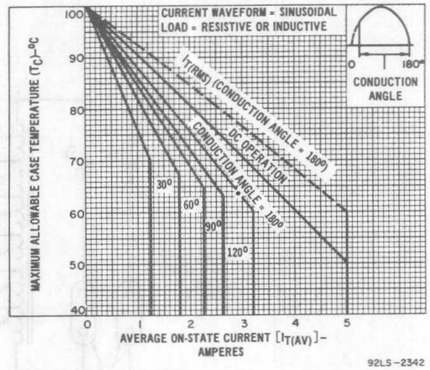


Fig. 9—Rating chart (case temperature).

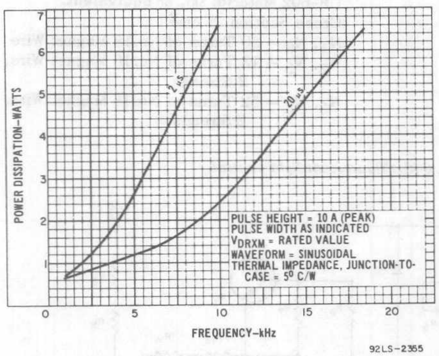


Fig. 10—Power dissipation versus frequency.

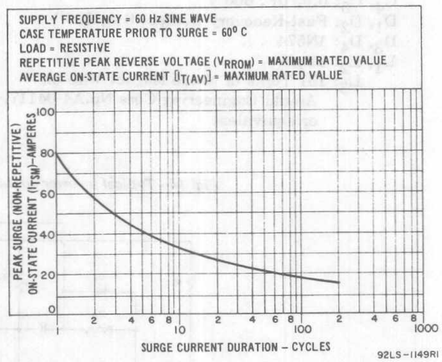


Fig. 11—Surge current rating.

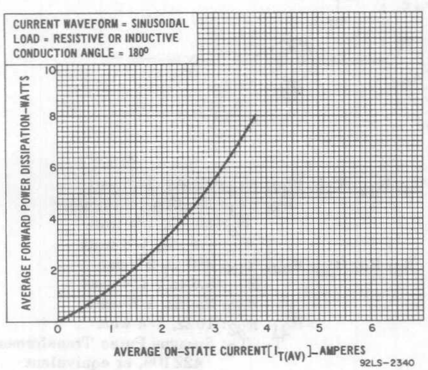


Fig. 12—Power dissipation versus average on-state current.

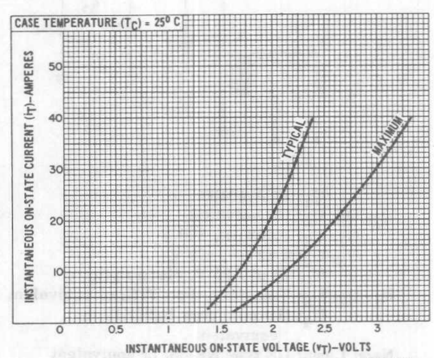
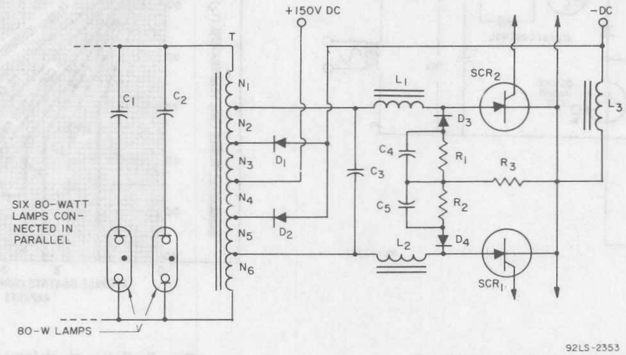


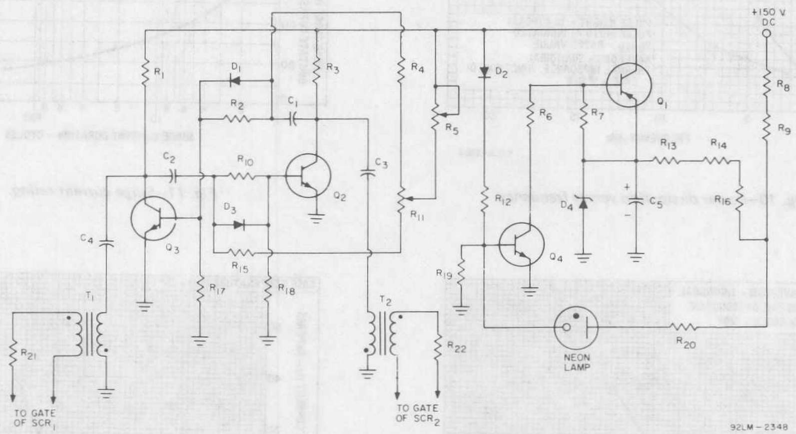
Fig. 13—On-state characteristics.



C_1, C_2: 0.01 μF, 1200 V (Ballast Capacitors)
C_3: 0.01 μF, 600 V
C_4, C_5: 0.02 μF, 600 V
D_1, D_2: Fast-Recovery Diodes, 6 A, 600 V
D_3, D_4: 1N574
L_1, L_2: 32 μH
L_3: 131 Turns of No.15 Magnet Wire on Arnold Engineering Core No.A4-04117, or equivalent

R_1, R_2: 1.2 kΩ, 5 W
R_3: 200 Ω, 10 W
T: Core, 8 pieces of Indiana General No. CF-602 Material 05, or equivalent. Cross Section, 8 cm^2
N_1, N_6 – 30 Turns of No.18 Magnet Wire
N_2, N_5 – 13 Turns of No.18 Magnet Wire, 2 Strands
N_3, N_4 – 52 Turns of No.18 Magnet Wire, 2 Strands

Fig. 14—Typical inverter circuit for 500-watt, 8-kHz fluorescent-light control.

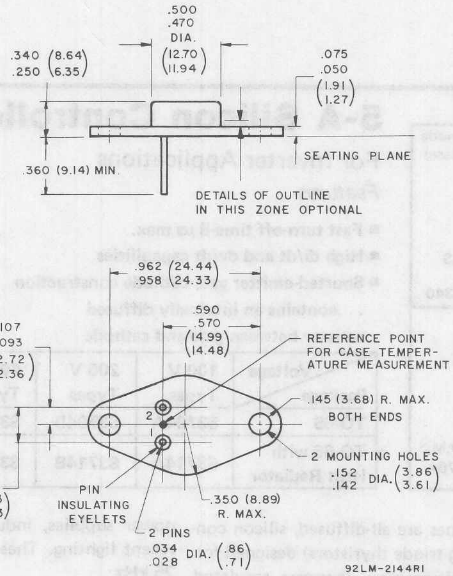


Q_1: RCA-40438
Q_2, Q_3, Q_4: RCA-2N3053
C_1, C_2: 0.003 μF, 100 V
C_3, C_4: 0.02 μF, 100 V
C_5: 25 μF, 25 V, electrolytic
D_1, D_2, D_3: Transitron type T1G, or equivalent
D_4: Motorola type 1M20Z10, or equivalent
Neon Lamp: GE type NE-83, or equivalent
R_1, R_3: 1 kΩ, 1/4 watt
R_2, R_{10}: 180 kΩ, 1/4 watt

R_4, R_{12}, R_{15}, R_{17}, R_{18}: 22 kΩ, 1/4 watt
R_5, R_{11}: 10 kΩ potentiometer
R_6: 10 kΩ, 1/4 watt
R_7: 1.5 kΩ, 1/4 watt
R_8, R_9, R_{13}, R_{14}, R_{16}: 680 Ω, 2 watts
R_{19}: 5.6 kΩ, 1/4 watt
R_{20}: 33 kΩ, 1/4 watt
R_{21}, R_{22}: 10 Ω, 1/4 watt
T_1, T_2: Sprague Pulse Transformer type 42Z109, or equivalent

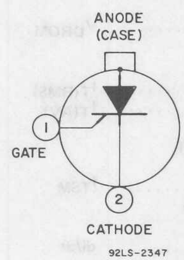
Fig. 15—Typical trigger pulse generator for 500-watt, 8-kHz fluorescent-light control inverter circuit.

DIMENSIONAL OUTLINE



Note: Dimensions in parentheses are in millimeters and are derived from the basic inch dimensions as indicated.

TERMINAL DIAGRAM



Pin 1: Gate
Pin 2: Cathode
Case: Anode

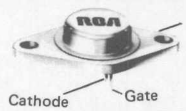
RCA
Solid State
Division

Thyristors

S3704A S3714A
S3704B S3714B
S3704D S3714D
S3704M S3714M
S3704S S3714S

5-A Silicon Controlled Rectifiers

For Inverter Applications



S3704A,B,D,M,S

JEDEC TO-66 H-1340

JEDEC TO-66 With Integral Heat Radiator S3714A,B,D,M,S H-1470A

Features

- Fast turn-off time-8 μs max.
- High di/dt and dv/dt capabilities
- Shorted-emitter gate-cathode construction . . .contains an internally diffused resistor between gate and cathode
- Center gate construction. . . .provides rapid uniform gate-current spreading for faster turn-on with substantially reduced heating effects

Package \ Voltage	100 V Types	200 V Types	400 V Types	600 V Types	700 V Types
TO-66	S3704A	S3704B	S3704D	S3704M	S3704S
TO-66 with Heat Radiator	S3714A	S3714B	S3714D	S3714M	S3714S

RCA-S3704 and S3714-series types are all-diffused, silicon controlled rectifiers (reverse-blocking triode thyristors) designed for inverter applications such as ultrasonics, choppers, regulated power supplies, induction heaters, cycloconverters, and fluorecent lighting. These types may be used at frequencies up to 25 kHz.

MAXIMUM RATINGS, *Absolute-Maximum Values:*		S3704A S3714A	S3704B S3714B	S3704D S3714D	S3704M S3714M	S3704S S3714S	
NON-REPETITIVE PEAK REVERSE VOLTAGE:■ Gate Open	V_{RSOM}	150	300	500	700	800	V
NON-REPETITIVE PEAK OFF-STATE VOLTAGE:■ Gate Open	V_{DSOM}	150	300	500	700	800	V
REPETITIVE PEAK REVERSE VOLTAGE:■ Gate Open	V_{RROM}	100	200	400	600	700	V
REPETITIVE PEAK OFF-STATE VOLTAGE:■ Gate Open	V_{DROM}	100	200	400	600	700	V
ON-STATE CURRENT: $T_C = 60^\circ C$, conduction angle = 180°:							
RMS	$I_{T(RMS)}$			← 5 →			A
Average	$I_{T(AV)}$			← 3.2 →			A
For other conditions				← See Figs. 2, 3, 4 →			
PEAK SURGE (NON-REPETITIVE) ON-STATE CURRENT: For one full cycle of applied principal voltage 60 Hz (sinusoidal)	I_{TSM}			← 80 →			A
For more than one full cycle of applied principal voltage				← See Fig. 5 →			
RATE OF CHANGE OF ON-STATE CURRENT $V_D = V_{DROM}$, $I_{GT} = 50$ mA, $t_r = 0.1$ μs (See Fig. 11)	di/dt			← 200 →			A/μs
FUSING CURRENT (for SCR protection): $T_J = -40$ to $100^\circ C$, t = 1 to 8.3 ms	I^2t			← 25 →			A
GATE POWER DISSIPATION:●							
Peak Forward (for 10 μs max., See Fig. 9)	P_{GM}			← 13 →			W
Peak Reverse (for 10 μs max., See Fig. 8)	P_{RGM}			← 13 →			W
Average (averaging time = 10 ms max.)	$P_{G(AV)}$			← 0.5 →			W
TEMPERATURE RANGE:▲							
Storage	T_{stg}			← −40 to 150 →			°C
Operating (Case)	T_C			← −40 to 100 →			°C
PIN TEMPERATURE (During soldering): At distances ≥ 1/32 in. (0.8 mm) from seating plane for 10 s max.	T_P			← 225 →			°C

■ These values do not apply if there is a positive gate signal. Gate must be open or negatively biased.
● Any product of gate current and gate voltage which results in a gate power less than the maximum is permitted.
▲ For temperature measurement reference point, *see Dimensional Outline.*

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ELECTRICAL CHARACTERISTICS

At Maximum Ratings Unless Otherwise Specified and at Indicated Case Temperature (T_C)

CHARACTERISTIC	SYMBOL	LIMITS FOR ALL TYPES Except as Specified MIN.	TYP.	MAX.	UNITS
Peak Off-State Current: (Gate open, $T_C = 100^\circ C$) Forward Current (I_{DOM}) at $V_D = V_{DROM}$ .... Reverse Current (I_{ROM}) at $V_R = V_{RROM}$	 I_{DOM} I_{ROM}	 – –	 0.5 0.3	 3 1.5	mA
Instantaneous On-State Voltage: $i_T = 30$ A (peak), $T_C = 25^\circ C$ .... For other conditions	v_T	–	2.2	3 See Fig. 7	V
Instantaneous Holding Current: Gate open, $T_C = 25^\circ C$	i_{HO}	–	20	50	mA
Critical Rate of Rise of Off-State Voltage (See Fig. 12): $V_D = V_{DROM}$, exponential voltage rise, Gate open, $T_C = 80^\circ C$	dv/dt	100	250	–	V/μs
DC Gate Trigger Current: $V_D = 12$ V (dc), $R_L = 30\ \Omega$, $T_C = 25^\circ C$ .... For other conditions	I_{GT}	–	15	40 See Fig. 9	mA
DC Gate Trigger Voltage: $V_D = 12$ V (dc), $R_L = 30\ \Omega$, $T_C = 25^\circ C$ .... For other conditions	V_{GT}	–	1.8	3.5 See Fig. 9	V
Gate Controlled Turn-On Time: (Delay Time + Rise Time) For $V_{DX} = V_{DROM}$, $I_{GT} = 300$ mA, $t_r = 0.1\ \mu s$, $I_T = 2$ A (peak), $T_C = 25^\circ C$ (See Fig. 10)	t_{gt}	–	0.7	–	μs
Circuit Commutated Turn-Off Time: $V_{DX} = V_{DROM}$, $i_T = 2$ A, pulse duration = 50 μs, dv/dt = 100 V/μs, –di/dt = –10 A/μs, $I_{GT} = 100$ mA, $V_{GT} = 0$ V (at turn-off), $T_C = 80^\circ C$ (See Fig. 13) ...	t_q	–	4	8	μs
Thermal Resistance, Junction-to-Case	$R_{\theta JC}$	–	–	8	°C/W

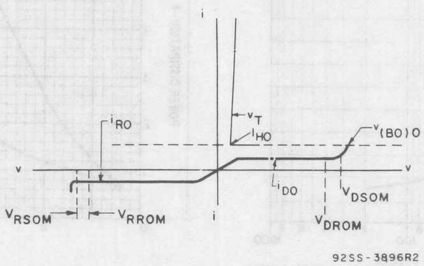


Fig. 1 – Principal voltage-current characteristic.

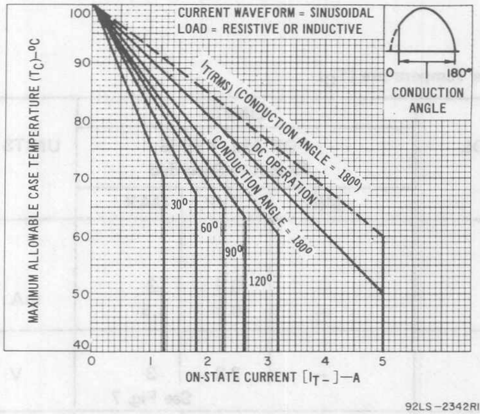


Fig. 2 — Maximum allowable case temperature vs. on-state current.

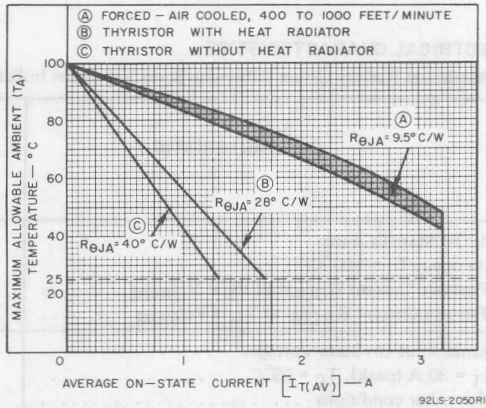


Fig. 3 — Maximum allowable ambient temperature vs. average on-state current.

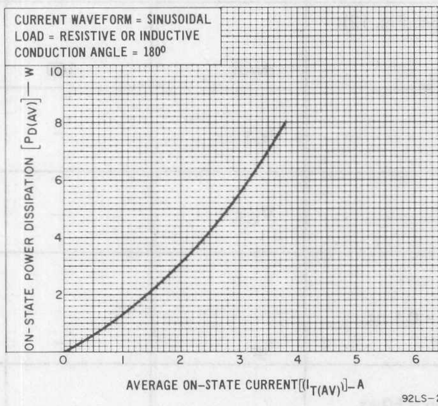


Fig. 4 — Power dissipation vs. average on-state current.

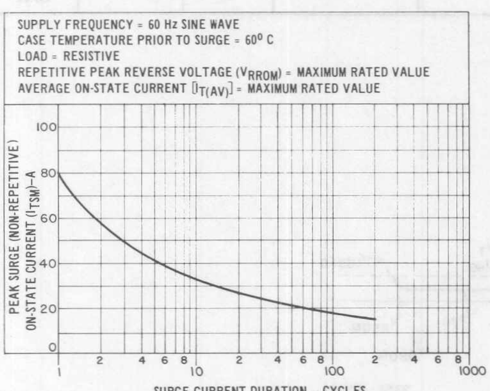


Fig. 5 — Peak surge on-state current vs. surge current duration.

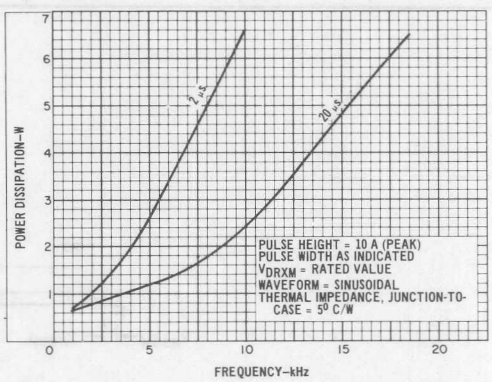


Fig. 6 — Dissipation vs. frequency.

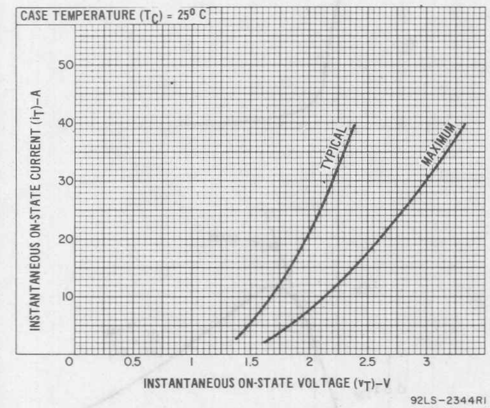


Fig. 7 – Instantaneous on-state current vs. on-state voltage.

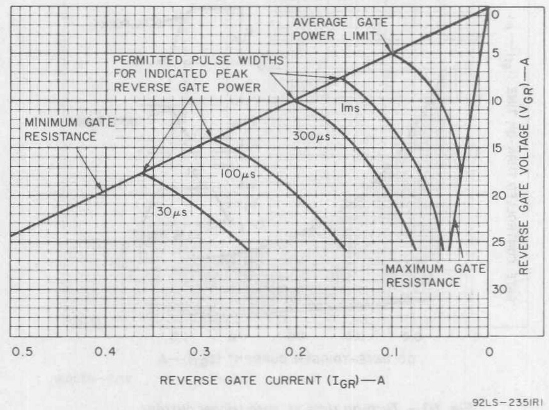


Fig. 8 – Reverse gate voltage vs. reverse gate current.

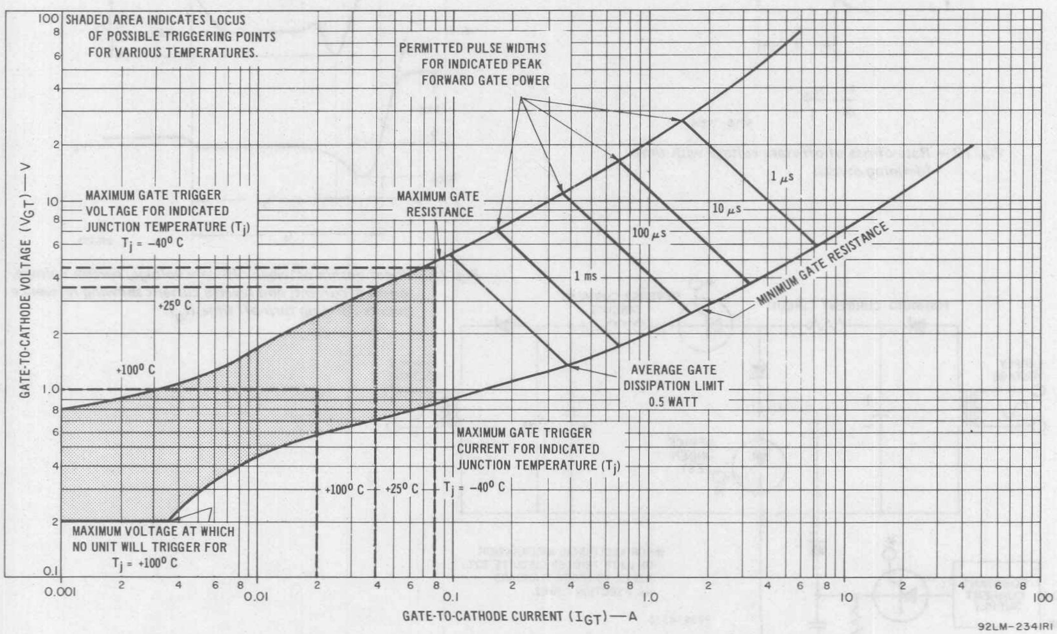


Fig. 9 – Gate trigger characteristics and limiting conditions for determination of permissible gate-trigger pulses.

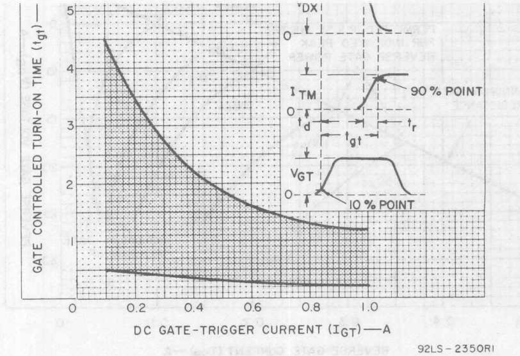


Fig. 10 — Turn-on time vs. gate-trigger current.

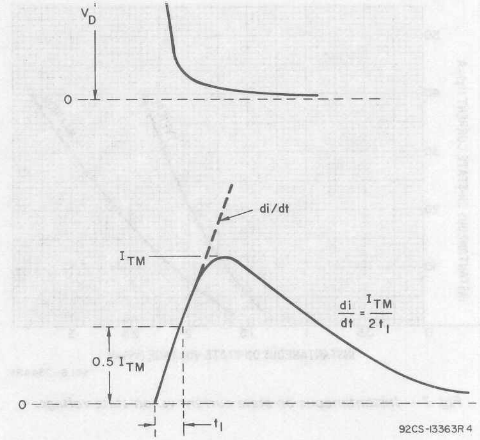


Fig. 11 — Rate-of-change of on-state current with time (defining di/dt).

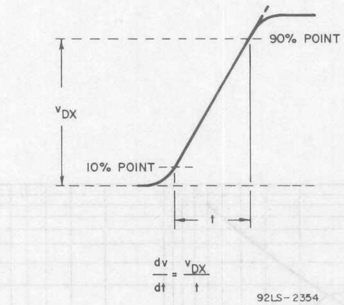


Fig. 12 — Rate-of-rise of off-state voltage with time (defining dv/dt).

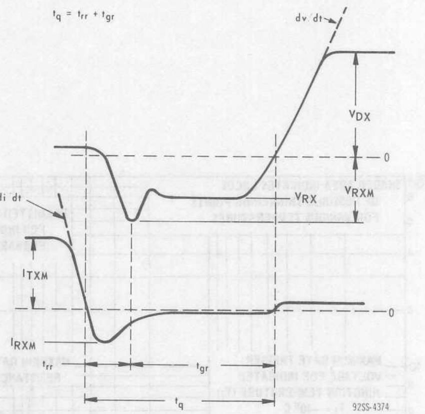


Fig. 13 — Relationship between off-state voltage, reverse voltage, on-state current, and reverse current showing reference points defining turn-off time (t_q).

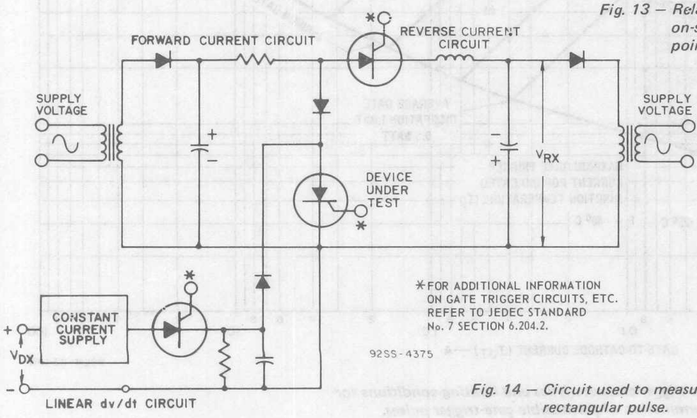
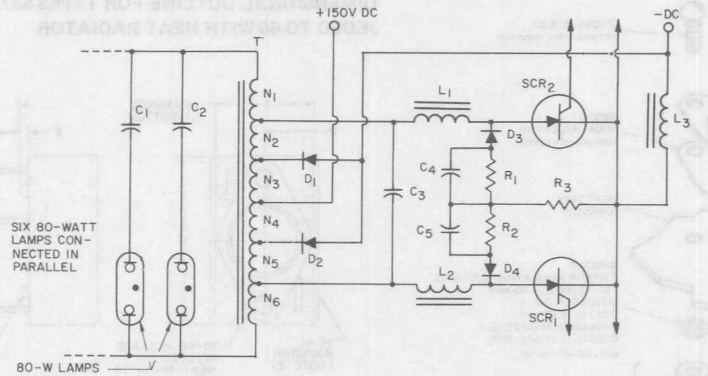


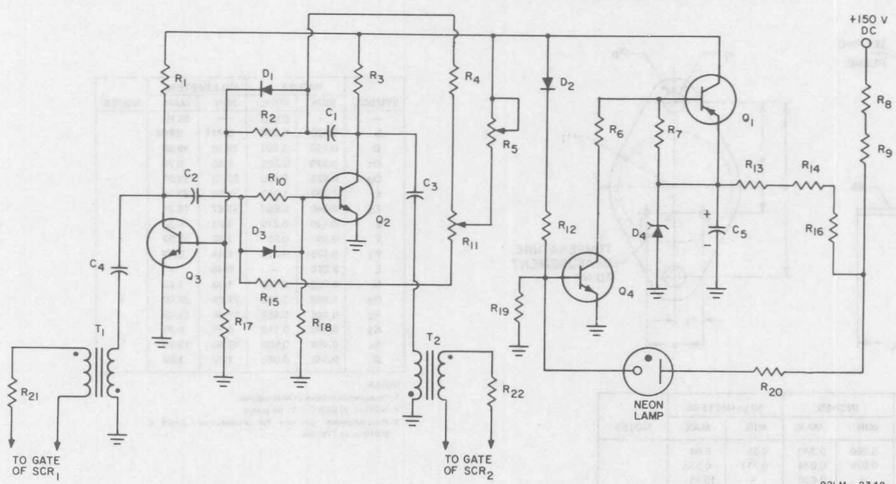
Fig. 14 — Circuit used to measure turn-off time (t_q), rectangular pulse.



C_1, C_2: 0.01 μF, 1200 V (Ballast Capacitors)
C_3: 0.01 μF, 600 V
C_4, C_5: 0.02 μF, 600 V
D_1, D_2: Fast-Recovery Diodes, 6 A, 600 V
D_3, D_4: 1N574
L_1, L_2: 32 μH
L_3: 131 Turns of No.15 Magnet Wire on Arnold Engineering Core No.A4-04117, or equivalent

R_1, R_2: 1.2 kΩ, 5 watt
R_3: 200 Ω, 10 watt
T: Core, 8 pieces of Indiana General No. CF-602 Material 05, or equivalent. Cross Section, 8 cm^2
N_1, N_6 – 30 Turns of No.18 Magnet Wire
N_2, N_5 – 13 Turns of No.18 Magnet Wire, 2 Strands
N_3, N_4 – 52 Turns of No.18 Magnet Wire, 2 Strands

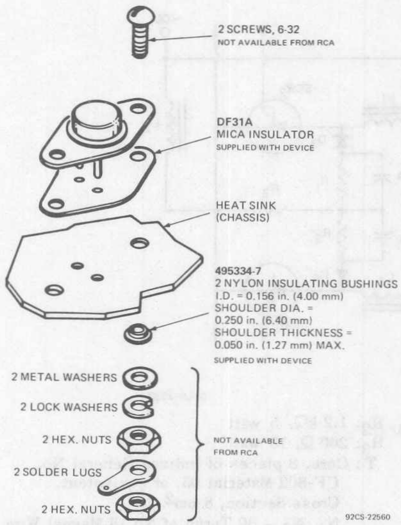
Fig. 15 – Typical inverter circuit for 500-W, 8-kHz fluorescent-light control.



Q_1: RCA-40438
Q_2, Q_3, Q_4: RCA-2N3053
C_1, C_2: 0.003 μF, 100 V
C_3, C_4: 0.02 μF, 100 V
C_5: 25 μF, 25 V, electrolytic
D_1, D_2, D_3: Transitron type T1G, or equivalent
D_4: Motorola type 1M20Z10, or equivalent
Neon Lamp: GE type NE-83, or equivalent
R_1, R_3: 1 kΩ, 1/4 watt
R_2, R_{10}: 180 kΩ, 1/4 watt

R_4, R_{12}, R_{15}, R_{17}, R_{18}: 22 kΩ, 1/4 watt
R_5, R_{11}: 10 kΩ potentiometer
R_6: 10 kΩ, 1/4 watt
R_7: 1.5 kΩ, 1/4 watt
R_8, R_9, R_{13}, R_{14}, R_{16}: 680 Ω, 2 watts
R_{19}: 5.6 kΩ, 1/4 watt
R_{20}: 33 kΩ, 1/4 watt
R_{21}, R_{22}: 10 Ω, 1/4 watt
T_1, T_2: Sprague Pulse Transformer type 42Z109, or equivalent

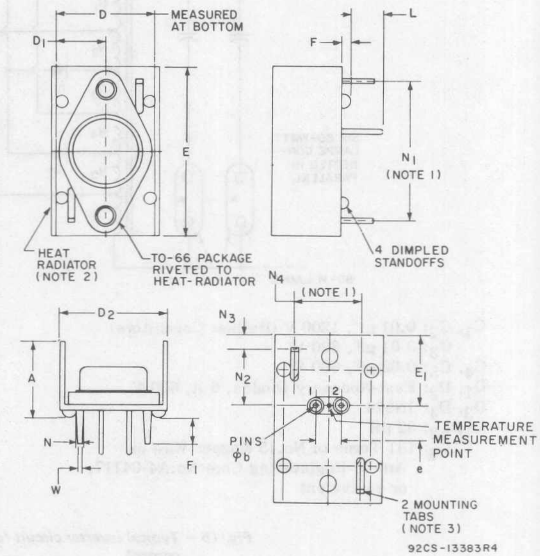
Fig. 16 – Typical trigger-pulse generator for 500-W, 8-kHz fluorescent-light control inverter circuit.



In the United Kingdom, Europe, Middle East, and Africa, mounting-hardware policies may differ; check the availability of all items shown with your RCA sales representative or supplier.

Fig. 17 – Suggested mounting hardware for types S3704A,B,D,M, and S.

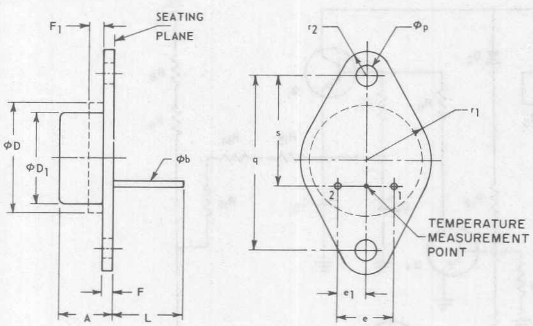
DIMENSIONAL OUTLINE FOR TYPES S3714A, B, C, D, M, and S JEDEC TO-66 WITH HEAT RADIATOR



SYMBOL	INCHES MIN.	INCHES MAX.	MILLIMETERS MIN.	MILLIMETERS MAX.	NOTES
A	–	0.620	–	15.75	
φb	0.028	0.034	0.711	0.864	
D	0.750	0.760	19.05	19.30	
D_1	0.370	0.385	9.40	9.78	
D_2	0.820	0.920	20.83	23.37	
E	1.297	1.327	32.94	33.70	
E_1	0.546	0.566	13.87	14.37	
e	0.190	0.210	4.83	5.33	
F	0.30	0.55	7.62	13.97	
F_1	0.175	0.210	4.44	5.33	
L	0.270	–	6.86	–	
N	0.052	0.065	1.32	1.65	
N_1	1.098	1.102	27.89	27.99	1
N_2	0.448	0.452	11.38	11.47	
N_3	0.099	0.113	0.25	0.29	
N_4	0.498	0.502	12.65	12.75	
W	0.048	0.060	1.22	1.52	

NOTES:
1. Measured at bottom of heat radiator.
2. 0.035 in. (0.889) C.R.S., tin plated.
3. Recommended hole size for printed-circuit board is 0.070 in. (1.778) dia.

DIMENSIONAL OUTLINE FOR TYPES S3704A, B, D, M and S JEDEC TO-66



SYMBOL	INCHES MIN.	INCHES MAX.	MILLIMETERS MIN.	MILLIMETERS MAX.	NOTES
A	0.250	0.340	6.35	8.64	
φb	0.028	0.034	0.711	0.863	
φD	–	0.620	–	15.75	
ϕD_1	0.470	0.500	11.94	12.70	
e	0.190	0.210	4.83	5.33	
e_1	0.093	0.107	2.36	2.72	
F	0.050	0.075	1.27	1.91	2
F_1	–	0.050	–	1.27	1
L	0.360	–	9.14	–	
φp	0.142	0.152	3.61	3.86	
q	0.958	0.962	24.33	24.43	
r_1	–	0.350	–	8.89	
r_2	–	0.145	–	3.68	
s	0.570	0.590	14.48	14.99	

NOTES:
1. The outline contour is optional within zone defined by φD and F_1.
2. Dimension does not include sealing flange.

92SS-3738

TERMINAL CONNECTIONS

Pin No. 1 – Gate

Pin No. 2 – Main Terminal 1

Case/Heat Radiator – Main Terminal 2

RCA Solid State Division

Thyristors/Rectifiers

S3705M D2600EF S3706M D2601DF D2601EF

SILICON CONTROLLED-RECTIFIER AND SILICON RECTIFIER COMPLEMENT

For Horizontal Deflection Circuits of Large-Screen Color-TV Receivers

S3705M
S3706M

JEDEC TO-66

H-1340

D2600EF
D2601DF
D2601EF

JEDEC DO-26

H-1157

These RCA devices are silicon controlled rectifiers and silicon rectifiers intended for use in horizontal-deflection circuits of large-screen color-television receivers. A simplified schematic diagram for the utilization of these SCR's and silicon rectifiers is shown below. For detailed information on the operation of this new deflection circuit, see Application Note AN-3780.

The S3705M (40640)* silicon controlled-rectifier and the D2601EF (40642)* silicon rectifier are the trace circuit components. They provide bipolar switching action for controlling the horizontal yoke current during the picture tube beam-trace interval.

The S3706M (40641)* silicon controlled-rectifier and the D2601DF (40643)* silicon rectifier are the commutating (retrace) circuit components. They control the yoke current during the retrace interval.

The D2600EF (40644)* silicon rectifier is used as a clamp in the trace circuit to protect the circuit components from excessively high voltages which may result from possible arcing in the picture tube or high-voltage rectifier.

*Numbers in parentheses (e.g. 40640) are former RCA type numbers.

Features:

- **Designed for off-the-line operation: B+ = 155 V**
- **Supply voltages: 108 to 129 V ac**
- **Outstanding performance and reliability**
- **High picture-tube beam current capability: to 1.5mA dc average (max.)**
- **Can fully deflect picture tubes having deflection angles to 90°, 1-7/16" neck diameters, and 25-kV ultor voltages (nom. value)**

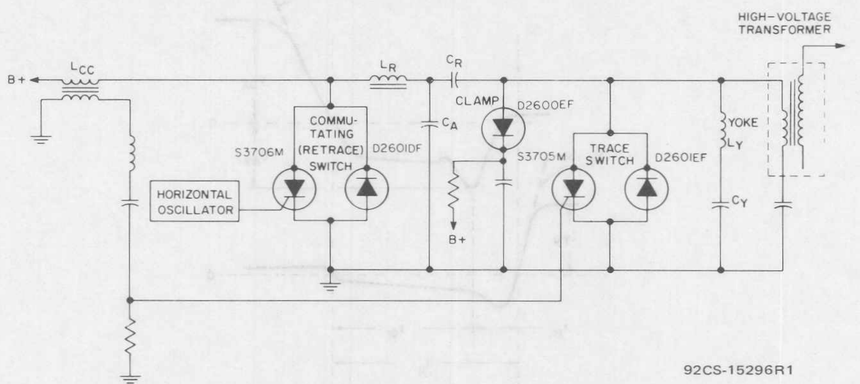


Fig. 1 – Simplified schematic-diagram of horizontal output circuit.

11-73

		Trace SCR	Commutating SCR	
Repetitive Peak Off-State Voltage				
With gate open	V_{DROM}	600		V
Repetitive Peak Reverse Voltage				
With gate open	V_{RROM}	5		V
On-State Current:				
For case temperature of +60°C and 60 Hz				
Average DC at 180° conduction angle. . . .	$I_{T(AV)}$	3.2		A
RMS	$I_{T(RMS)}$	5		A
Peak Surge (Non-Repetitive) On-State Current:				
For one cycle of 60 Hz voltage	I_{TSM}	80		A
Critical Rate of Rise of On-State Current:				
For $V_{DX} = V_{(BO)O}$ rated value, I_{GT} = 50 mA, 0.1 μs rise time	di/dt	200		A/μs
Gate Power Dissipation[a]:				
Peak (forward or reverse) for 10 μs duration	P_{GM}	25		W
Temperature Range[b]:				
Storage	T_{stg}	-40 to +150		°C
Operating (case)	T_C	-40 to +100		°C

[a] Any values of peak gate current or peak gate voltage to give the maximum gate power are permissible.

[b] For information on the reference point of temperature measurement, see *Dimensional Outline*.

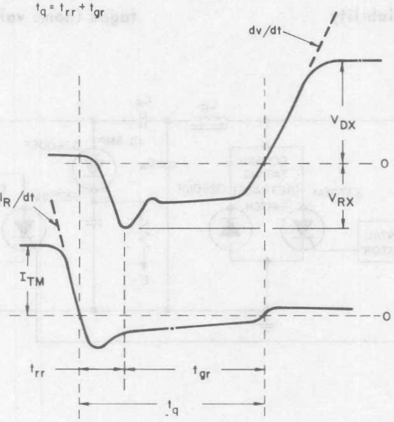


Fig. 2 – Waveshape of t_q characteristic for types S3705M and S3706M.

SILICON CONTROLLED-RECTIFIERS

Characteristics at Maximum Ratings (unless otherwise specified), and at Indicated Case Temperature (T_C)

CHARACTERISTIC:		S3705M Trace SCR Min.	Typ.	Max.	S3706M Commutating SCR Min.	Typ.	Max.	UNIT
Breakover Voltage:								
With gate open								
At $T_C = +100^oC$	$V_{(BO)O}$	–	–	–	400	–	–	V
At $T_C = +80^oC$	$V_{(BO)O}$	550	–	–	–	–	–	V
Peak Forward Off-State Current:								
With gate open, $V_{DO} = V_{(BO)O}$ rated value								
At $T_C = +100^oC$	I_{DOM}	–	–	–	–	0.5	1.5	mA
At $T_C = +80^oC$	I_{DOM}	–	0.5	1.5	–	–	–	mA
Instantaneous On-State Voltage:								
For an on-state current of 30 A, $T_C = +25^oC$	v_T	–	2.2	3	–	2.2	3	V
DC Gate Trigger Current:								
At $T_C = +25^oC$	I_{GT}	–	15	30	–	15	30	mA(dc)
DC Gate Trigger Voltage:								
At $T_C = +25^oC$	V_{GT}	–	1.8	4	–	1.8	4	V(dc)
Thermal Resistance:								
Junction-to-Case	$R_{\theta JC}$	–	–	4	–	–	4	$^oC/W$
Circuit-Commutated Turn-Off Time: (Reverse recovery time + gate recovery time)								
Trace SCR— At $I_{TM} = 6$ A ($t_r = 25\,\mu s$, $di/dt = 2.5$ A/μs), $V_D = 0$ V (prior to turn on), $V_D = 400$ V (reapplied at 175 V/μs), $V_R = 0.8$ V (min.), $I_{GT} = 100$ mA, V_{GK}(bias) = -30 V (68 Ω source), f = 15.75 kHz, $T_C = 70^oC$	t_q	–	–	2.5	–	–	–	μs
Commutating SCR— At $I_{TM} = 13$ A (½ sine wave 7 μs base, initial di/dt = 20 A/μs to 3 A), $V_D = 350$ V (prior to turn on), dV/dt = 400 V/μs (to 100 V), $V_R = 0.8$ V (min.), $I_{GT} = 100$ mA ($t_p = 3\,\mu s$, $t_r = 0.2\,\mu s$), V_{GK}(bias) = -2.5 V (47 Ω source during turn off), f = 15.75 kHz, $T_C = 70^oC$	t_q	–	–	–	–	–	4.5	μs

SILICON RECTIFIERS

MAXIMUM RATINGS:		D2601EF *Trace*	D2601DF *Commutating*	D2600EF *Clamp*	
			Silicon Rectifiers		
Non-Repetitive Peak Reverse Voltage[c]	V_{RM}(nonrep)	700	800	700	V
Repetitive Peak Reverse Voltage[d]	V_{RM}(rep)	550	450	550	V
Forward Current:[d]					
DC	I_F	1	1	1	A
RMS	$I_{F(RMS)}$	1.9	1.6	0.2	A
Peak Repetitive	$I_{FM(rep)}$	6.5	6	0.3	A
Peak Surge[e]	$I_{FM(surge)}$	70	10	20	A
Ambient Temperature Range:					
Operating	T_A		-40 to +150		^{o}C
Storage	T_{stg}		-40 to +175		^{o}C
Lead Temperature:					
For 10 seconds maximum			255		^{o}C
CHARACTERISTICS:					
Max. Instantaneous Forward Voltage Drop:					
At I_F = 4 A, $T_A \leqq 75^{o}C$	v_{FM}	1.3	1.3	2	V
Max. Reverse Current (Static):[f]					
At T_C = 100°C	I_{RM}	0.25	0.25	0.25	mA
At T_A = 25°C	I_{RM}	10	10	10	μA
Reverse Recovery Time:					
At I_F = 20 mA, I_R = 1 mA, T_C = 25°C	t_{rr}	1.1	1.1	1.6	max μs
Turn-On Time:					
At I_F = 20 mA, T_C = 25°C	t_{on}	0.3	0.3	0.3	max μs
Peak Turn-On Voltage:					
At I_F = 20 mA, T_C = 25°C		5	6	7	max V

[c] Pulse width = 10 μs, pulse repetition rate = 15.7 kHz, 3 pulses.

[d] For ambient temperatures up to 45°C and maximum thermal resistance from reference point to ambient of 45°C/W, with devices operating in circuit of Fig.1.

[e] Pulse width = 3 ms.

[f] At max. peak reverse voltage and zero forward current.

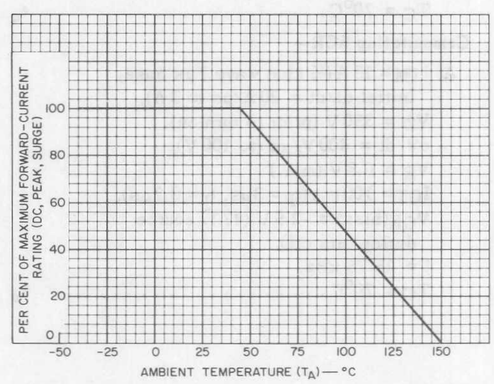
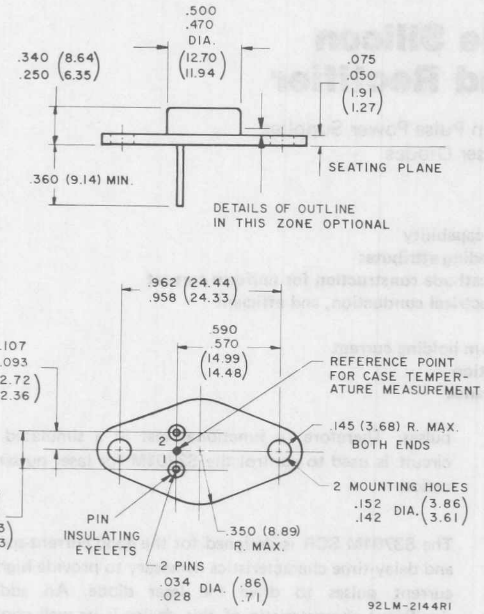


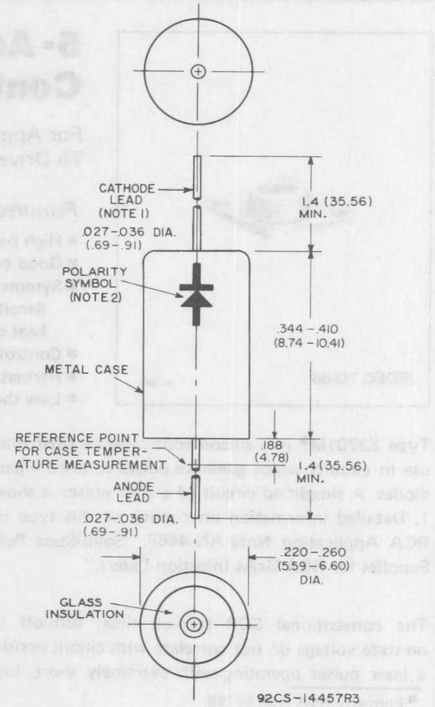
Fig. 3 – Rating chart for types D2600EF, D2601DF, and D2601EF.

DIMENSIONAL OUTLINES

S3705M, S3706M
JEDEC TO-66



D2600EF, D2601DF, D2601EF
JEDEC DO-26



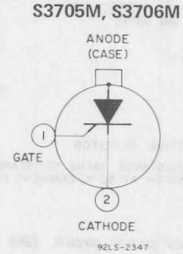
Note 1: Connected to metal case.

Note 2: Arrow indicates direction of forward (easy) current flow as indicated by dc ammeter.

Dimensions in parentheses are in millimeters and are derived from the basic inch dimensions as indicated.

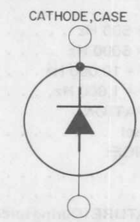
TERMINAL DIAGRAMS

S3705M, S3706M



Pin 1: Gate
Pin 2: Cathode
Case: Anode

D2600EF, D2601DF, D2601EF



When incorporating RCA Solid State Devices in equipment, it is recommended that the designer refer to "Operating Considerations for RCA Solid State Devices", Form No. 1CE-402, available on request from RCA Solid State Division, Box 3200, Somerville, N.J. 08876.

RCA
Solid State
Division

Thyristors

S3701M

JEDEC TO-66

H-1340

5-Ampere Silicon Controlled Rectifier

For Applications in Pulse Power Supplies
To Drive GaAs Laser Diodes

Features:

- High peak-current capability
- Good current-spreading attributes
- Symmetrical gate-cathode construction for uniform current density, rapid electrical conduction, and efficient heat dissipation
- Controlled minimum holding current
- Hermetic construction
- Low thermal resistance

Type S3701M● is a silicon controlled rectifier intended for use in circuits which generate pulses to drive injection laser diodes. A simplified circuit of a laser pulser is shown in Fig. 1. Detailed information on circuits of this type is given in RCA Application Note AN-4469, "Solid-State Pulse Power Supplies for RCA GaAs Injection Lasers."

The conventional SCR turn-on time, turn-off time, and on-state voltage do not correlate with circuit performance in a laser pulser operating with extremely short, high-current pulses. Therefore, a functional test in a simulated pulser circuit is used to control the S3701M for laser pulser application.

The S3701M SCR is designed for the good current-spreading and delay-time characteristics necessary to provide high-peak-current pulses to drive the laser diode. An additional significant characteristic of this device is its well controlled holding current, which assures operation only at currents sufficiently high to meet the circuit requirements.

● Formerly RCA type 40768.

MAXIMUM RATINGS, *Absolute-Maximum Values:*
Case temperature (T_C) = 25°C, unless otherwise specified

REPETITIVE PEAK OFF-STATE VOLTAGE:			
Gate open	V_{DROM}	600	V
RMS ON-STATE CURRENT (Conduction angle = 180°)	$I_{T(RMS)}$	5	A
REPETITIVE PEAK ON-STATE CURRENT (0.2 μs Pulse Width):	I_{PM}		
Free-air cooling, f = 500 Hz		75	A
Free-air cooling, f = 5000 Hz		40	A
Infinite heat sink, f = 10,000 Hz		40	A
Infinite heat sink, f = 1,000 Hz		75	A
GATE POWER DISSIPATION:			
PEAK (For 10 μs pulse)	P_{GM}	25	W
TEMPERATURE RANGE:			
Storage	T_{stg}	-40 to 125	°C
Operating (Case)	T_C	-40 to 100	°C
TERMINAL TEMPERATURE (During soldering):	T_T		
For 10 s max. (terminals and case)		225	°C

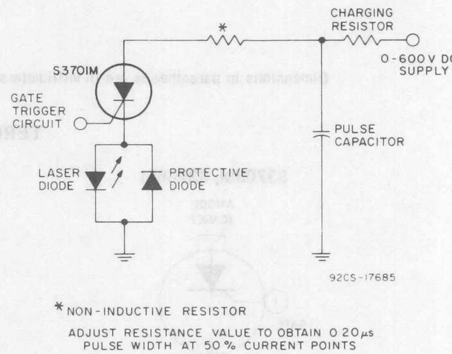


Fig. 1—Simplified laser pulser circuit. (See AN-4469 for specific circuits.)

ELECTRICAL CHARACTERISTICS

At Maximum Ratings and at Indicated Case Temperature (T_C) Unless Otherwise Specified

CHARACTERISTIC	SYMBOL	LIMITS Min.	LIMITS Max.	UNITS
Peak Off-State Current: Gate open, $v_D = V_{DROM}$, $T_C = 25^oC$	I_{DROM}	–	0.65	mA
$T_C = 75^oC$		–	1.2	
DC Gate-Trigger Current: $T_C = 25^oC$	I_{GT}	–	35	mA
DC Gate-Trigger Voltage: $T_C = 25^oC$	V_{GT}	–	4	V
DC Holding Current: Gate open, $T_C = 25^oC$	I_{HO}	15	–	mA
$T_C = 75^oC$		10	–	
Critical Rate-of-Rise of Off-State Voltage: For $v_D = V_{DROM}$, exponential voltage rise, gate open, $T_C = 75^oC$	dv/dt	200	–	V/μs
Source Voltage for Functional Test (See Fig. 2): $I_p = 75A$, $C = 0.022\mu F$, $R_s = 2\Omega$, f = 60Hz, pulse duration = $0.2\mu s$, $T_C = 25^oC$	V_s	–	550	V
Thermal Resistance: Junction-to-Case	$R_{\theta JC}$	–	7	$^oC/W$
Junction-to-Ambient	$R_{\theta JA}$	–	40	

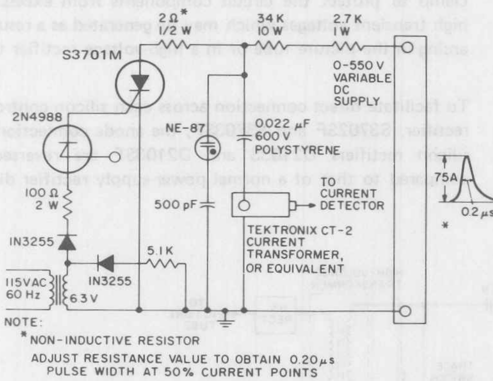


Fig. 2–Functional test circuit.

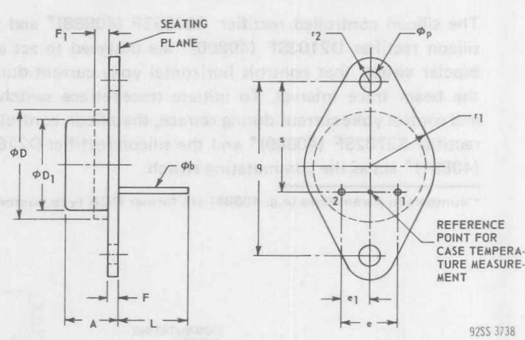
TERMINAL CONNECTIONS

Pin 1 – Gate

Pin 2 – Cathode

Mounting Flange, Case – Anode

DIMENSIONAL OUTLINE (JEDEC TO-66)



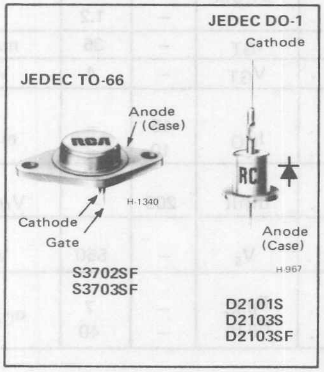
SYMBOL	INCHES MIN.	INCHES MAX.	MILLIMETERS MIN.	MILLIMETERS MAX.	NOTES
A	0.250	0.340	6.35	8.64	
φb	0.028	0.034	0.711	0.863	
φD		0.620		15.75	
φD_1	0.470	0.500	11.94	12.70	
e	0.190	0.210	4.83	5.33	
e1	0.093	0.107	2.36	2.72	
F	0.050	0.075	1.27	1.91	2
F_1		0.050		1.27	1
L	0.360		9.14		
φp	0.142	0.152	3.61	3.86	
q	0.958	0.962	24.33	24.43	
r1		0.350		8.89	
r2		0.145		3.68	
s	0.570	0.590	14.48	14.99	

NOTES:
1. The outline contour is optional within zone defined by φ D and F_1.
2. Dimension does not include seating flanges.

RCA Solid State Division

Thyristors/Rectifiers

S3702SF D2101S
S3703SF D2103S
D2103SF



Horizontial-Deflection SCR's and Rectifiers

For 110° Large-Screen Color TV

Features:

- **Operation from supply voltages between 150 and 270 V (nominal).**
- **Ability to handle high beam current; average 1.6 mA dc.**
- **Ability to supply as much as 7 mJ of stored energy to the deflection yoke, which is sufficient for 29 mm-neck picture tubes, as well as 36.5 mm-neck tubes, both operated at 25 kV (nominal value).**
- **Highly reliable circuit which can also be used as a low-voltage power supply.**

These RCA types are designed for use in a horizontal output circuit such as that shown in Fig. 1.

The silicon controlled rectifier S3703SF (40888)* and the silicon rectifier D2103SF (40890)* are designed to act as a bipolar switch that controls horizontal yoke current during the beam trace interval. To initiate trace-retrace switching and control yoke current during retrace, the silicon controlled rectifier S3702SF (40889)* and the silicon rectifier D2103S (40891)* act as the commutating switch.

*Numbers in parentheses (e.g. 40888) are former RCA type numbers.

The silicon rectifier D2101S (40892)* may be used as a clamp to protect the circuit components from excessively high transient voltages which may be generated as a result of arcing in the picture tube or in a high-voltage rectifier tube.

To facilitate direct connection across each silicon controlled rectifier, S3702SF and S3703SF, the anode connections of silicon rectifiers D2103S and D2103SF are reversed as compared to that of a normal power-supply rectifier diode.

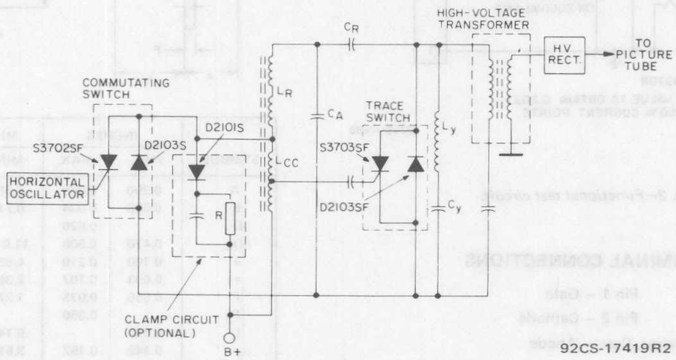


Fig. 1 – Simplified schematic diagram of horizontal output circuit.

For a description of the operation of SCR deflection systems see RCA Application Note AN-3780, "A New Horizontal Deflection System Using S3705M and S3706M Silicon Controlled Rectifiers"; ST-3871; "An SCR Horizontal-Sawtooth-Current and High-Voltage Generator for Magnetically Deflected Picture Tubes"; ST-3835, "Switching-Device Requirements for a New Horizontal-Deflection System".

MAXIMUM RATINGS, ***Absolute-Maximum Values:***

SILICON CONTROLLED RECTIFIERS

		TRACE SCR S3703SF	COMMUTATING SCR S3702SF	
Non-Repetitive Peak Off-State Voltage:				
Gate open	V_{DSOM}	800*	750*	V
Repetitive Peak Off-State Voltage:				
Gate open	V_{DROM}			
T_C = 80°C		750	700	V
Repetitive Peak Reverse Voltage:				
Gate open	V_{RROM}	25	25	V
On-State Current:				
T_C = 60°C, 50 Hz sine wave, conduction angle = 180°:				
Average DC	$I_{T(AV)}$	3.2	3.2	A
RMS	$I_{T(RMS)}$	5	5	A
Peak Surge (Non-Repetitive):				
For one cycle of applied voltage, 50 Hz	I_{TSM}	50	50	A
Critical Rate of Rise of On-State Current:				
For $V_D = V_{DROM}$ rated value, I_{GT} = 50 mA, 0.1 µs rise time	di/dt	200	200	A/µs
Gate Power Dissipation●:				
Peak (forward or reverse) for 10 µs duration, max. reverse gate bias = −35 V	P_{GM}	25	25	W
Temperature Range■:				
Storage	T_{stg}	−40 to 150		°C
Operating (case)	T_C	−40 to 80		°C

*Protection against transients above this value must be provided. Transients generated by arcing may persist for as long as 10 cycles.

●Any product of gate current and gate voltage which results in a gate power less than the maximum is permitted.

■Temperature measurement point is shown on the DIMENSIONAL OUTLINE.

ELECTRICAL CHARACTERISTICS, ***At Maximum Ratings and at Indicated Case Temperature (T_C)***

SILICON CONTROLLED RECTIFIERS

CHARACTERISTIC	SYMBOL	LIMITS S3703SF TYP.	S3703SF MAX.	S3702SF TYP.	S3702SF MAX.	UNITS
Peak Forward Off-State Current: Gate open, V_{DO} = Rated V_{DROM}, T_C = 85°C	I_{DOM}	0.5	1.5	0.5	1.5	mA
Instantaneous On-State Voltage: i_T = 20 A, T_C = 25°C	v_T	2.2	3	2.2	3	V
DC Gate Trigger Current: T_C = 25°C	I_{GT}	15	40	15	45	mA
DC Gate Trigger Voltage: T_C = 25°C	V_{GT}	1.8	4	1.8	4	V
Critical Rate-of Rise of Off-State Voltage: T_C = 70°C	dv/dt	700 (MIN.)▲		700 (MIN.)▲		V/µs
Circuit-Commutated Turn-Off Time†: T_C = 70°C, Minimum negative bias during turn-off time = −20 V (S3703SF) and −2.5 V (S3702SF)						
Rate of Reapplied Voltage (dv/dt) = 175 V/µs	t_q	–	2.4	–	–	µs
Rate of Reapplied Voltage (dv/dt) = 400 V/µs		–	–	–	4.2	µs
Thermal Resistance: Junction-to-Case	$R_{\theta JC}$	–	4	–	4	°C/W

▲ Up to 500 V max. See Fig. 3.

† This parameter, the sum of reverse recovery time and gate recovery time, is measured from the zero crossing of current to the start of the reapplied voltage. Knowledge of the current, the reapplied voltage, and the case temperature is necessary when measuring t_q. In the worst conditions (high line, zero-beam, off-frequency, minimum auxiliary load, etc.), turn-off time must not fall below the given values. Turn-off time increases with temperature; therefore, case temperature must not exceed 70°C. See Figs. 2 & 3.

MAXIMUM RATINGS, *Absolute-Maximum Values:*

SILICON RECTIFIERS

		TRACE D2103SF	COMMUTATING D2103S	CLAMP D2101S	
REVERSE VOLTAGE**:					
Non-repetitive peak●●	V_{RSM}	750	700	700	V
Repetitive peak	V_{RRM}	800	800	800	V
FORWARD CURRENT:					
RMS	$I_{F(RMS)}$	3■■	3■■	1	A
Peak-surge (non-repetitive)●●	I_{FSM}	70	70	30	A
Peak (repetitive)	I_{FRM}	7	12	0.5	A
TEMPERATURE RANGE:					
Storage	T_{stg}		−30 to 150		^{o}C
Operating (Case)	T_C		−30 to 80		^{o}C
LEAD TEMPERATURE▲▲:					
For 10 s maximum	T_L		225		^{o}C

** For ambient temperatures up to 45°C.
●● For a maximum of 3 pulses, 10 μs in duration, during any 64 μs period.
■■ Maximum current rating applies only if the rectifier is properly mounted to maintain junction temperature below 150°C. See Fig. 4.
▲▲ At distances no closer to rectifier body than points A and B on outline drawing.

ELECTRICAL CHARACTERISTICS
SILICON RECTIFIERS

CHARACTERISTIC	SYMBOL	MAXIMUM LIMITS D2103S D2103SF	MAXIMUM LIMITS D2101S	UNITS
Reverse Current: Static				
For V_{RRM} = max. rated value, I_F = 0, T_C = 25°C	I_{RM}	10	–	μA
For V_R = 500 V, T_C = 100 °C		250		
Instantaneous Forward Voltage Drop: At I_F = 4 A, T_A = 75°C	v_F	1.4	1.5	V
Reverse-Recovery Time: I_{FM} = 3.14 A, ½ sinewave, −di/dt = − 10 A/μs, pulse duration = 0.94 μs, T_C = 25°C	t_{rr}	0.5	0.7	μs

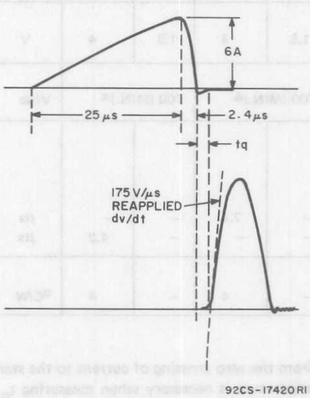


Fig. 2 – Circuit-commutated turn-off in the trace SCR S3703SF.

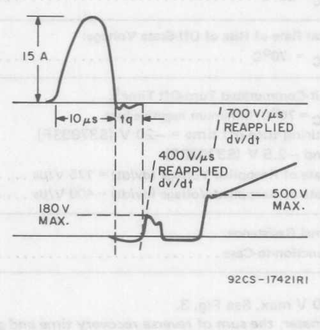
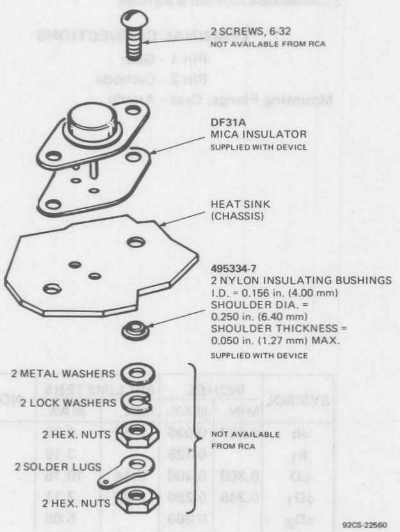


Fig. 3 – Circuit-commutated turn-off time in the commutating SCR S3702SF.

MOUNTING SCR's AND RECTIFIERS

The SCR's and rectifiers can be operated at full current only if they have adequate heat sinking. The procedure illustrated in Fig. 4 should be used when mounting the SCR's. A single aluminum plate made as shown in Fig. 5 will provide adequate heat sinking for trace and commutating rectifiers. Lip punching of the chassis at one end of the clamp plate, makes it possible to mount the rectifier using only one screw.

S3702SF and S3703SF fit socket PTS-4 (United International Dynamics Corp., 2029 Taft St., Hollywood, Fla.), or equivalent.



In the United Kingdom, Europe, Middle East, and Africa, mounting-hardware policies may differ; check the availability of all items shown with your RCA sales representative or supplier.

Fig.4—Suggested hardware and mounting arrangement for SCR's S3702SF and S3703SF.

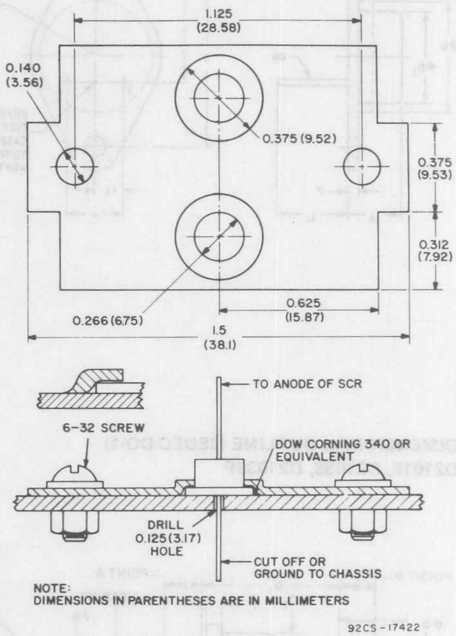
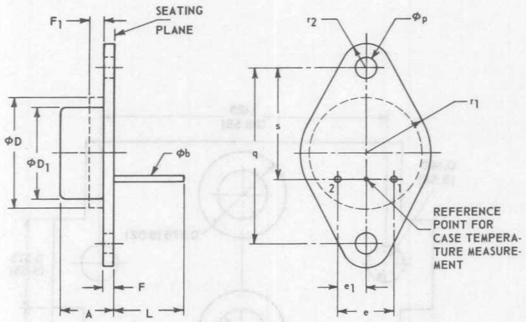


Fig.5—Suggested clamp plate and mounting arrangement for rectifiers D2103S and D2103SF.

DIMENSIONAL OUTLINE (JEDEC TO-66)
S3702SF, S3703SF



SYMBOL	INCHES		MILLIMETERS		NOTES
	MIN.	MAX.	MIN.	MAX.	
A	0.250	0.340	6.35	8.64	
ϕb	0.028	0.034	0.711	0.863	
ϕD	—	0.620	—	15.75	
ϕD_1	0.470	0.500	11.94	12.70	
e	0.190	0.210	4.83	5.33	
e_1	0.093	0.107	2.36	2.72	
F	0.050	0.075	1.27	1.91	2
F_1	—	0.050	—	1.27	1
L	0.360	—	9.14	—	
ϕp	0.142	0.152	3.61	3.86	
q	0.958	0.962	24.33	24.43	
r_1	—	0.350	—	8.89	
r_2	—	0.145	—	3.68	
s	0.570	0.590	14.48	14.99	

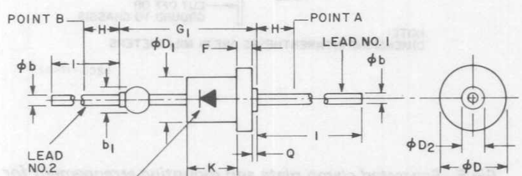
NOTES:
1. The outline contour is optional within zone defined by ϕD and F_1.
2. Dimensions does not include seating flanges.

92SS-3738

TERMINAL CONNECTIONS

Pin 1 - Gate
Pin 2 - Cathode
Mounting Flange, Case - Anode

DIMENSIONAL OUTLINE (JEDEC DO-1)
D2101S, D2103S, D2103SF



POLARITY SYMBOL INDICATES DIRECTION OF FORWARD (EASY) CURRENT FLOW. THIS POLARITY IS OPPOSITE TO RCA POWER SUPPLY RECTIFIERS.

92CS-17423

SYMBOL	INCHES		MILLIMETERS		NOTES
	MIN.	MAX.	MIN.	MAX.	
ϕb	0.027	0.035	0.69	0.89	2
b_1		0.125		3.18	1
ϕD	0.360	0.400	9.14	10.16	
ϕD_1	0.245	0.280	6.22	7.11	
ϕD_2		0.200		5.08	
F		0.075		1.91	
G_1		0.725		18.42	
K	0.220	0.260	5.59	6.60	
1	1.000	1.625	25.40	41.28	
Q		0.025		0.64	
H	0.5		12.7		

NOTES:
1. Dimension to allow for pinch or seal deformation anywhere along tubulation (optional).
2. Diameter to be controlled from free end of lead to within 0.188 inch (4.78 mm) from the point of attachment to the body. Within the 0.188 inch (4.78 mm) dimension, the diameter may vary to allow for lead finishes and irregularities.

TERMINAL CONNECTIONS

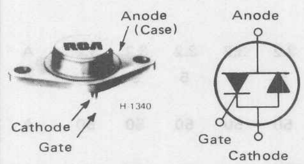
Lead No. 1 & Case – Anode
Lead No. 2 – Cathode

RCA
Solid State
Division

Thyristors / Rectifiers

S3800 Series

JEDEC TO-66



RCA-41017–41023

ITR's (Integrated Thyristor/Rectifiers)

Power Integrated Circuits for Color and Monochrome TV Horizontal Deflection

Application Features:

- **Operation from supply voltages between 150 and 270 V (nominal)**
- **Ability to handle high beam current (average 1.6 mA dc)**
- **Ability to supply as much as 7 mJ of stored energy to the deflection yoke, which is sufficient for 29-mm-neck picture tubes and 35-mm-neck picture tubes operated at 25 kV (nominal value)**
- **Highly reliable circuit that can also be used as a low-voltage power supply**

The S3800 series are all-diffused power integrated circuits that incorporate a silicon controlled rectifier and a silicon rectifier on a common pellet. S3800SF (41017)*, S3800MF (41018)*, and S3800E (41019)* are used as bipolar switches to control horizontal yoke current during the beam trace interval; S3800S (41020)*, S3800M (41021)*, S3800EF (41022)*, and S3800D (41023)* are used as commutating switches to initiate trace-retrace switching.

*Numbers in parentheses (e.g. 41017) are former RCA type numbers.

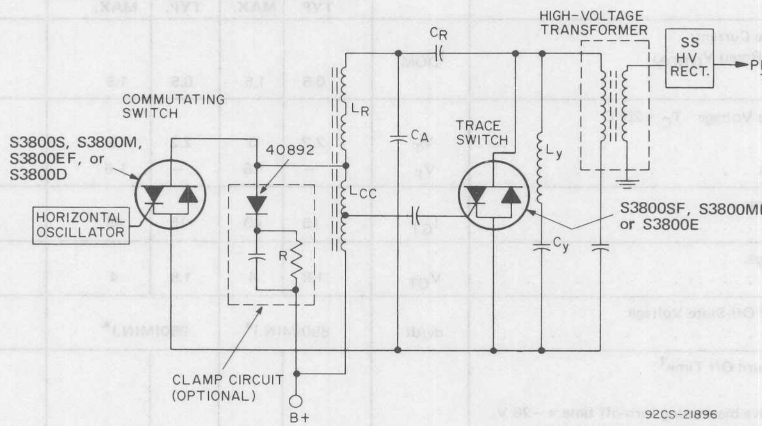


Fig. 1–Simplified schematic diagram of horizontal output circuit.

For a description of the operation of SCR deflection systems, see RCA Application Note AN-3780, "A New Horizontal Deflection System Using S3705M and S3706M Silicon Controlled Rectifiers"; ST-3871, "An SCR Horizontal-Sawtooth-Current and High-Voltage Generator for Magnetically Deflected Picture Tubes"; ST-3835, "Switching-Device Requirements for a New Horizontal-Deflection System".

MAXIMUM RATINGS, *Absolute-Maximum Values:*

		S3800SF	S3800MF	S3800E	S3800S	S3800M	S3800EF	S3800D	
Non-Repetitive Peak Off-State Voltage: Gate open	V_{DSOM}	800*	700*	550*	750*	650*	600*	500*	V
Repetitive Peak Off-State Voltage: Gate open	V_{DROM}								
$T_C = 80^oC$		750	650	500	700	600	550	400	V
Repetitive Peak Reverse Voltage: Gate open	V_{RROM}	0	0	0	0	0	0	0	V
On-State Current: $T_C = 60^oC$, 50 Hz sine wave, conduction angle = 180°:									
Average DC	$I_{T(AV)}$	3.2	3.2	3.2	3.2	3.2	3.2	3.2	A
RMS	$I_{T(RMS)}$	5	5	5	5	5	5	5	A
Peak Surge (Non-Repetitive): For one cycle of applied voltage, 50 Hz	I_{TSM}	50	50	50	50	50	50	50	A
Critical Rate of Rise of On-State Current: For $V_D = V_{DROM}$ rated value, I_{GT} = 50 mA, 0.1 μs rise time	di/dt	200	200	200	200	200	200	200	A/μs
Gate Power Dissipation: Peak (forward or reverse) for 10 μs duration; max. reverse gate bias = −35 V for S3800SF, MF, E; −8 V for S3800S, M, EF, D	P_{GM}	25	25	25	25	25	25	25	W
Temperature Range■: Storage	T_{stg}	−40 to 150							°C
Operating (case)	T_C	−40 to 80							°C

*Protection against transients above this value must be provided. Transients generated by arcing may persist for as long as 10 cycles.

■Temperature measurement point is shown on the DIMENSIONAL OUTLINE.

ELECTRICAL CHARACTERISTICS, *At Maximum Ratings and at Indicated Case Temperature (T_C)*

CHARACTERISTIC	SYMBOL	LIMITS S3800SF, S3800MF S3800E TYP.	MAX.	S3800S, S3800M, S3800EF, S3800D TYP.	MAX.	UNITS
Peak Forward Off-State Current: Gate open, V_{DO} = Rated V_{DROM}, $T_C = 85^oC$	I_{DOM}	0.5	1.5	0.5	1.5	mA
Instantaneous On-State Voltage: $T_C = 25^oC$ SCR, I_T = 30 A	V_T	2.2	3	2.2	3	V
Rectifier, I_F = 3 A	V_F	–	1.6	–	1.6	V
DC Gate Trigger Current: $T_C = 25^oC$	I_{GT}	15	40	15	45	mA
DC Gate Trigger Voltage: $T_C = 25^oC$	V_{GT}	1.8	4	1.8	4	V
Critical Rate of Rise of Off-State Voltage: $T_C = 70^oC$	dv/dt	850(MIN.)▲		850(MIN.)▲		V/μs
Circuit-Commutated Turn-Off Time†: $T_C = 70^oC$ Minimum negative bias during turn-off time = −20 V, rate of reapplied voltage (dv/dt) = 175 V/μs	t_q	–	2.4	–	–	μs
Minimum negative bias during turn-off time = −2.5 V, rate of reapplied voltage (dv/dt) = 400 V/μs	t_q			–	4.2	μs
Thermal Resistance: Junction-to-Case	$R_{\theta JC}$	–	4	–	4	°C/W

▲ Up to 500 V max. (with negative bias from −2.5 V to −4.0 V).

† This parameter, the sum of reverse recovery time and gate recovery time, is measured from the zero crossing of current to the start of the reapplied voltage. Knowledge of the current, the reapplied voltage, and the case temperature is necessary when measuring t_q. In the worst conditions (high line, zero-beam, off-frequency, minimum auxiliary load, etc.), turn-off time must not fall below the given values. Turn-off time increases with temperature; therefore, case temperature must not exceed 70°C.

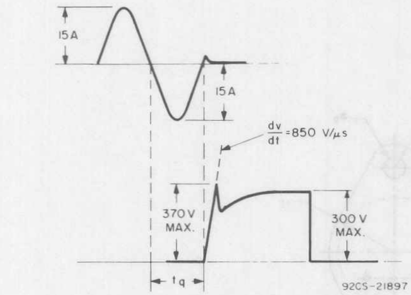


Fig. 2— Circuit-commutated turn-off time in commutating ITR.

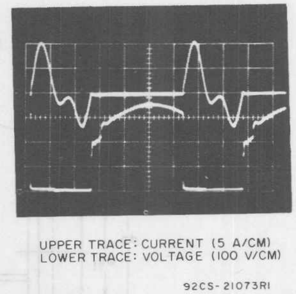


Fig. 3— Typical deflection-circuit waveforms for commutating ITR.

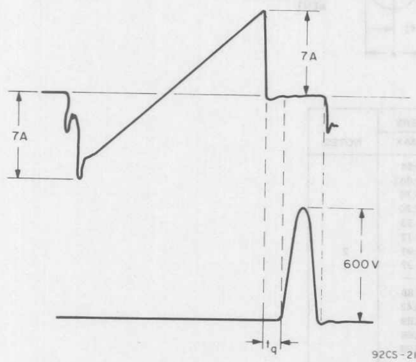


Fig. 4— Circuit-commutated turn-off time in trace ITR.

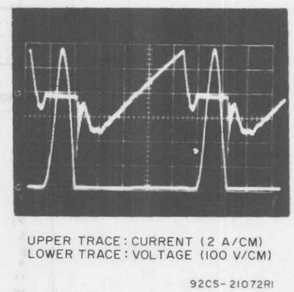
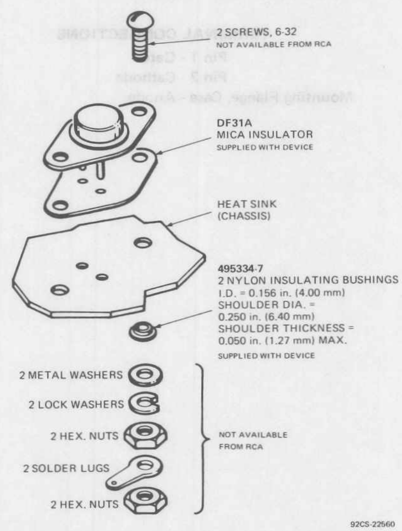
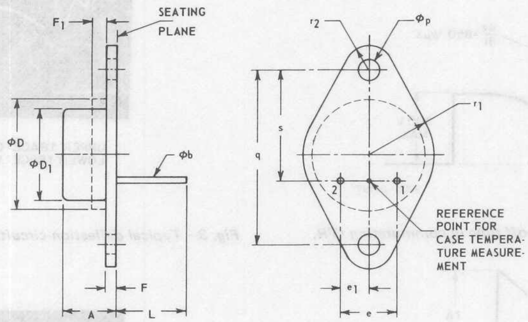


Fig. 5— Typical deflection-circuit waveforms for trace ITR.



In the United Kingdom, Europe, Middle East, and Africa, mounting-hardware policies may differ; check the availability of all items shown with your RCA sales representative or supplier.

Fig. 6— Suggested mounting arrangement for all types.



SYMBOL	INCHES MIN.	INCHES MAX.	MILLIMETERS MIN.	MILLIMETERS MAX.	NOTES
A	0.250	0.340	6.35	8.64	
ϕb	0.028	0.034	0.711	0.863	
ϕD	—	0.620	—	15.75	
ϕD_1	0.470	0.500	11.94	12.70	
e	0.190	0.210	4.83	5.33	
e_1	0.093	0.107	2.36	2.72	
F	0.050	0.075	1.27	1.91	2
F_1	—	0.050	—	1.27	1
L	0.360	—	9.14	—	
ϕp	0.142	0.152	3.61	3.86	
q	0.958	0.962	24.33	24.43	
r1	—	0.350	—	8.89	
r2	—	0.145	—	3.68	
s	0.570	0.590	14.48	14.99	

NOTES:
1. The outline contour is optional within zone defined by ϕD and F_1.
2. Dimension does not include sealing flanges.

92SS 3738

TERMINAL CONNECTIONS

Pin 1 - Gate
Pin 2 - Cathode
Mounting Flange, Case - Anode

All-Diffused SCR's for Low-Cost Power-Control and Power-Switching Applications

RCA 2N3668*, 2N3669*, 2N3670*, and 2N4103* are all-diffused, three-junction, silicon controlled-rectifiers (SCR's▲). They are intended for use in power-control and power-switching applications requiring a blocking voltage capability of up to 600 volts and a forward-current capability of 12.5 amperes (rms value) or 8 amperes (average value) at a case temperature of 80°C.

The 2N3668 is designed for low-voltage power supplies, the 2N3669 for direct operation from 120-volt line supplies, the 2N3670 for direct operation from 240-volt line supplies, and the 2N4103 for high-voltage power supplies.

* Formerly Dev. Types TA2621, TA2598, TA2618, and TA2775, respectively.

▲ The silicon controlled-rectifier is also known as a reverse-blocking triode thyristor.

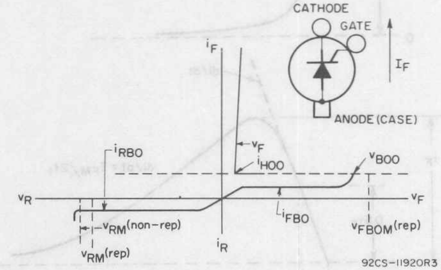
JEDEC TO-3

2N3668	For Low-Voltage Power Supplies
2N3669	For 120-Volt Line Operation
2N3670	For 240-Volt Line Operation
2N4103	For High-Voltage Power Supplies

FEATURES

- Low switching losses
- High di/dt and dv/dt capabilities
- Shorted emitter gate-cathode construction
- Forward and reverse gate dissipation ratings
- Designed especially for high-volume systems
- All-diffused construction – assures exceptional uniformity and stability of characteristics
- Direct-soldered internal construction – assures exceptional resistance to fatigue
- Symmetrical gate-cathode construction – provides uniform current density, rapid electrical conduction, and efficient heat dissipation
- All-welded construction and hermetic sealing
- Low leakage currents, both forward and reverse
- Low forward voltage drop at high current levels
- Low thermal resistance

TYPICAL E-I CHARACTERISTIC OF SILICON CONTROLLED-RECTIFIER



Absolute-Maximum Ratings, for Operation with Sinusoidal AC Supply Voltage at a Frequency between 50 and 400 Hz, and with Resistive or Inductive Load

RATINGS	CONTROLLED-RECTIFIER TYPES				UNITS
	2N3668	2N3669	2N3670	2N4103	
Transient Peak Reverse Voltage (Non-Repetitive), v_{RM}(non-rep)[a]	150	330	660	700	volts
Peak Reverse Voltage (Repetitive), v_{RM}(rep)[b]	100	200	400	600	volts
Peak Forward Blocking Voltage (Repetitive), v_{FBOM}(rep)[c]	600	600	600	700	volts
Forward Current: For case temperature (T_C) of +80° C					
Average DC value at a conduction angle of 180°, I_{FAV}[d]	8	8	8	8	amperes
RMS value, I_{FRMS}[e]	12.5	12.5	12.5	12.5	amperes
For other conditions, see Fig. 8					
Peak Surge Current, i_{FM}(surge)[f]: For one cycle of applied voltage	200	200	200	200	amperes
For more than one cycle of applied voltage	See Fig. 10	See Fig. 10	See Fig. 10	See Fig. 10	
Sub-Cycle Surge (Non-Repetitive), I^2t[g] For a period of 1 ms to 8.3 ms	165	165	165	165	ampere^2 second
Rate of Change of Forward Current, di/dt[h] $V_{FB} = v_{BOO}$ (min. value) I_{GT} = 200 mA, 0.5 μs rise time (See waveshapes of Fig. 1)	200	200	200	200	amperes microsecond
Gate Power*: Peak, Forward or Reverse, for 10 μs duration, P_{GM}[i] (See Figs. 5 and 6)	40	40	40	40	watts
Average, P_{GAV}[k]	0.5	0.5	0.5	0.5	watt
Temperature: Storage, T_{stg}●	−40 to +125	−40 to +125	−40 to +125	−40 to +125	°C
Operating (Case), T_C	−40 to +100	−40 to +100	−40 to +100	−40 to +100	°C

* Any values of peak gate current or peak gate voltage to give the maximum gate power is permissible.

● Temperature reference point is within 1/8" of the center of the underside of unit.

WAVESHAPE OF di/dt RATING TEST

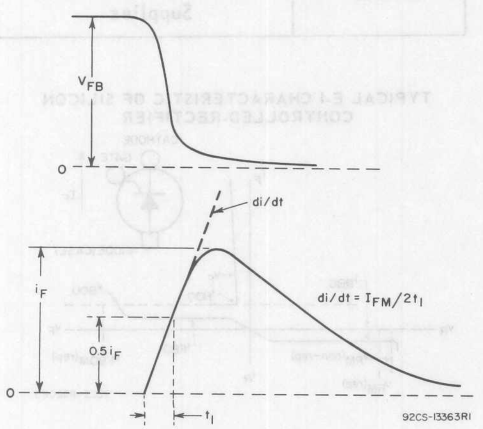


Fig. 1

WAVESHAPE OF CRITICAL dv/dt RATING TEST

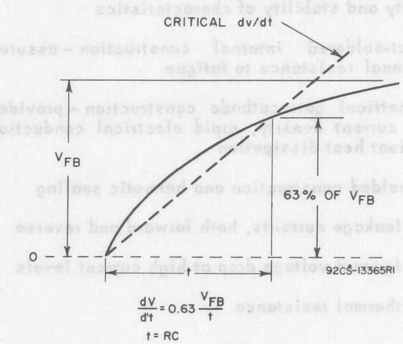


Fig. 2

Characteristics at Maximum Ratings (unless otherwise specified), and at Indicated Case Temperature (T_C)

CHARACTERISTICS	CONTROLLED-RECTIFIER TYPES												UNITS
	2N3668			2N3669			2N3670			2N4103			
	Min.	Typ.	Max.	Min.	Typ.	Max.	Min.	Typ.	Max.	Min.	Typ.	Max.	
Forward Breakover Voltage, v_{BOO}[m]													
At T_C = +100°C	100	–	–	200	–	–	400	–	–	600	–	–	volts
Peak Blocking Current, at T_C = +100°C:													
Forward, I_{FBOM}[n]	–	0.2	2	–	0.25	2.5	–	0.3	3	–	0.35	4	mA
V_{FBO}[p] = v_{BOO}(min. value)													
Reverse, I_{RBOM}[q]	–	0.05	1	–	0.1	1.25	–	0.2	1.5	–	0.3	3	mA
V_{RBO}[p] = v_{RM}(rep) value													
Forward Voltage Drop, v_F[r]													
At a Forward Current of 25 amperes and a T_C = +25°C (See Fig. 11)	–	1.5	1.8	–	1.5	1.8	–	1.5	1.8	–	1.5	1.8	volts
DC Gate-Trigger Current, I_{GT}[s]:													
At T_C = +25°C (See Fig. 5)	1	20	40	1	20	40	1	20	40	1	20	40	mA(dc)
Gate-Trigger Voltage, V_{GT}[t]:													
At T_C = +25°C (See Fig. 5)	–	1.5	2	–	1.5	2	–	1.5	2	–	1.5	2	volts (dc)
Holding Current, i_{HOO}[u]:													
At T_C = +25°C	0.5	25	50	0.5	25	50	0.5	25	50	0.5	25	50	mA
Critical Rate of Applied Forward Voltage,													
Critical dv/dt[v]	10	100	–	10	100	–	10	100	–	10	100	–	volts/ microsecond
V_{FB} = v_{BOO}(min. value), exponential rise, T_C = +100°C (See waveshape of Fig. 2)													
Turn-On Time, t_{on}[w], (Delay Time + Rise Time)	0.75	1.25	–	0.75	1.25	–	0.75	1.25	–	0.75	1.25	–	microseconds
V_{FB} = v_{BOO}(min. value), i_F = 8 amperes, I_{GT} = 200 mA, 0.1 μs rise time, T_C = +25°C (See waveshapes of Fig. 3)													
Turn-Off Time, t_{off}[x], (Reverse Recovery Time + Gate Recovery Time)	–	20	50	–	20	50	–	20	50	–	20	50	microseconds
i_F = 8 amperes, 50 μs pulse width, dv_{FB}/dt = 20 v/μs, di_r/dt = 30 A/μs, I_{GT} = 200 mA, T_C = +80°C (See waveshapes of Fig. 4)													
Thermal Resistance, Junction-to-Case	–	–	1.7	–	–	1.7	–	–	1.7	–	–	1.7	°C/W

WAVESHAPE OF t_{on} RATING TEST

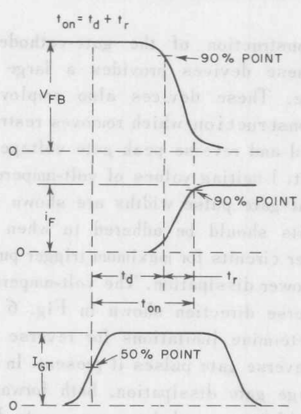


Fig. 3

WAVESHAPE OF t_{off} RATING TEST

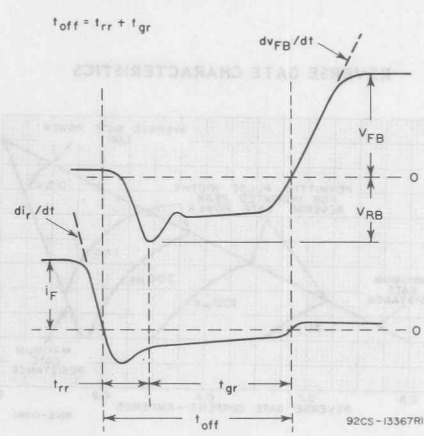


Fig. 4

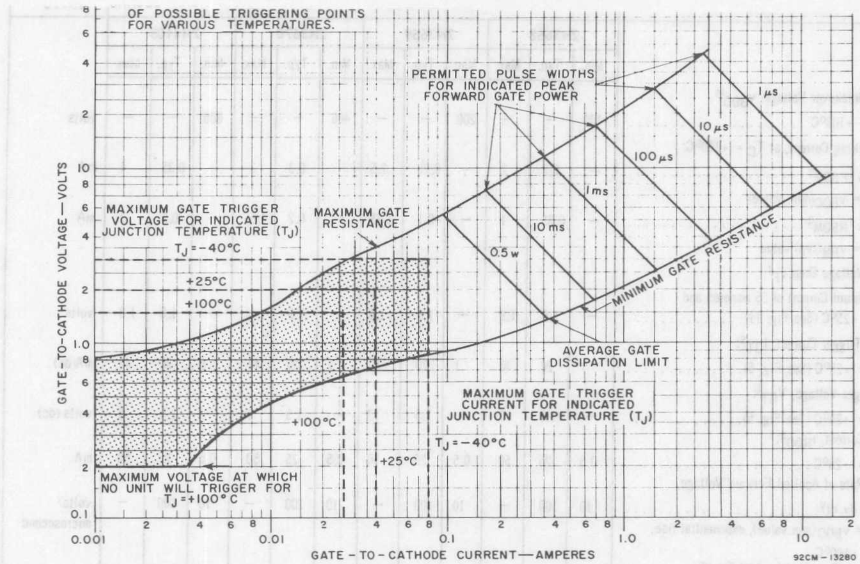


Fig. 5

REVERSE GATE CHARACTERISTICS

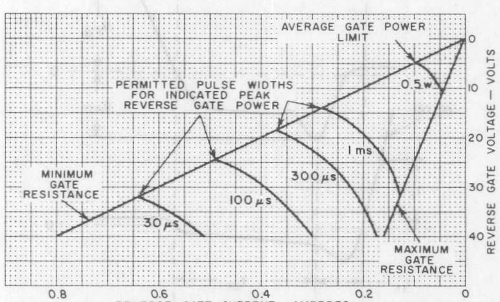


Fig. 6

TRIGGERING CONSIDERATIONS

The construction of the gate-cathode junction used in these devices provides a large periphery center gate. These devices also employ shorted-emitter construction which removes restrictions on both forward and reverse peak gate voltage and peak gate current. Limiting values of volt-ampere products for different gate pulse widths are shown in Fig. 5. These limits should be adhered to when designing pulse trigger circuits for maximum trigger pulse widths and peak power dissipation. The volt-ampere products in the reverse direction shown in Fig. 6 should be used to determine limitations for reverse gate transients or reverse gate pulses if present. In all cases, total average gate dissipation, both forward and reverse, should not exceed the average gate dissipation rating (P_{GAV}) of 0.5 watt.

Turn-on times for different gate currents are shown in Fig. 7. These curves may be used to determine the required width of the gate trigger pulses. It is only necessary to maintain the gate trigger pulse until the magnitude of the forward anode current has reached the latching current value. However, conservative design requires that the gate trigger pulse width be at least equal to or somewhat greater than the device turn-on time. Some applications may require wider gate pulse widths for proper circuit operation.

TURN-ON TIME CHARACTERISTICS

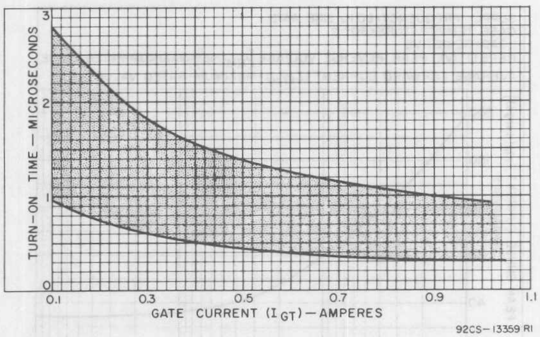


Fig. 7

RATING CHART (CASE TEMPERATURE)

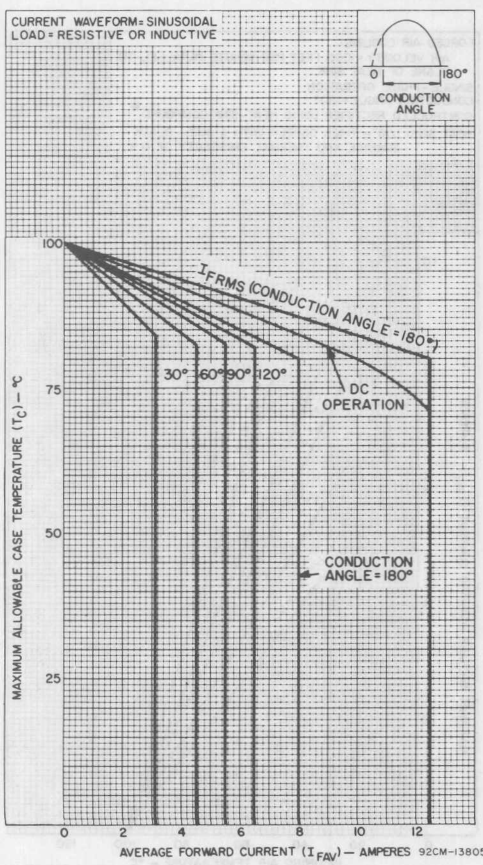


Fig. 8

POWER DISSIPATION

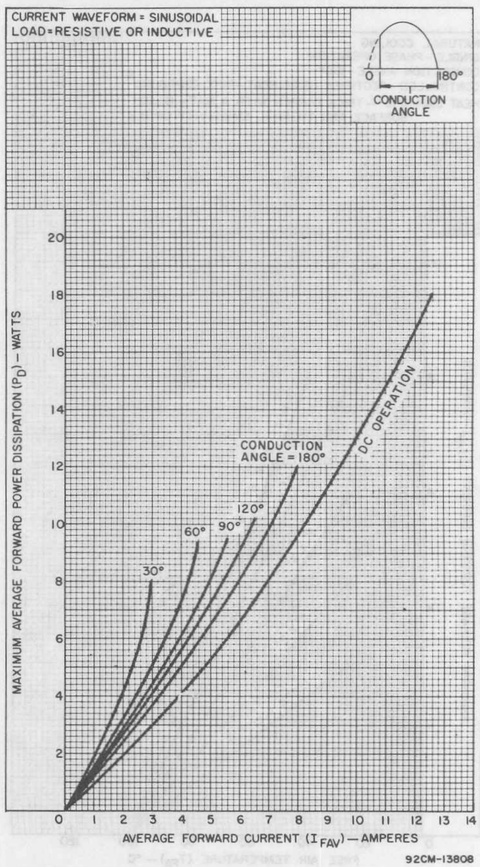


Fig. 9

SURGE CURRENT RATING

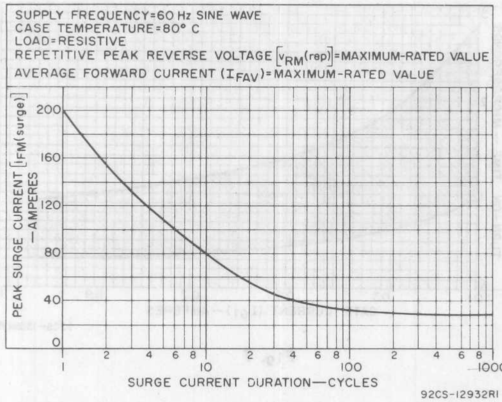


Fig. 10

FORWARD CHARACTERISTICS

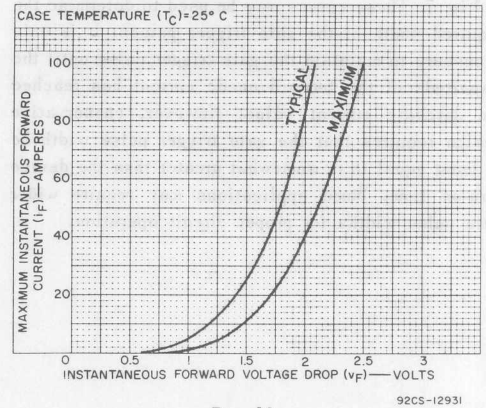


Fig. 11

NATURAL-AIR COOLING OPERATION GUIDANCE CHART

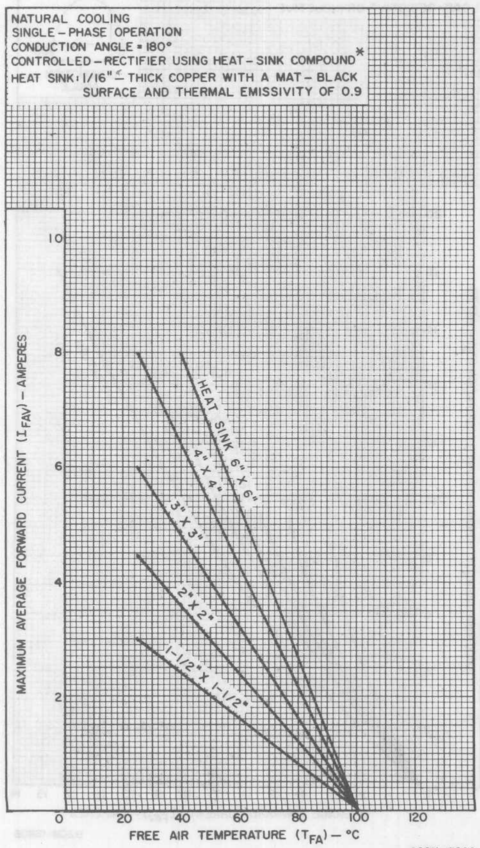


Fig. 12

FORCED-AIR COOLING OPERATION GUIDANCE CHART

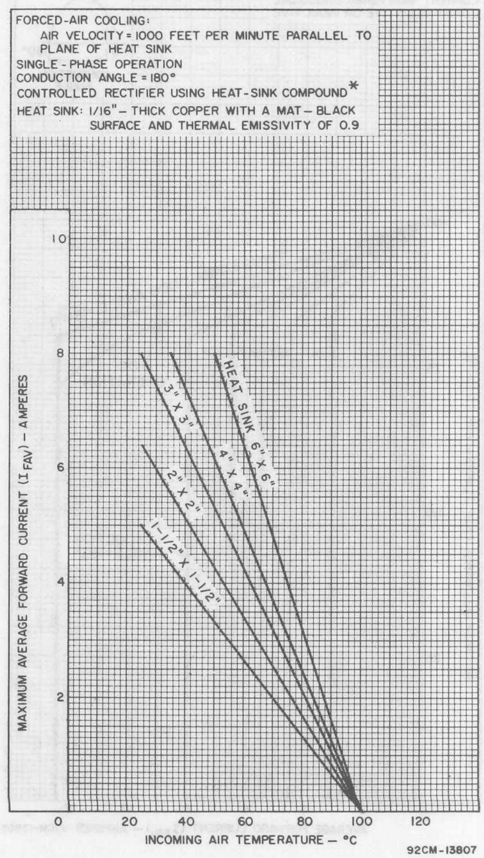


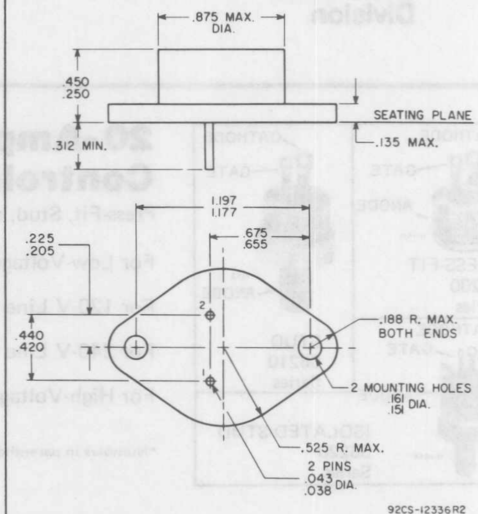
Fig. 13

*Dow Corning 340 Silicon Heat Sink Compound, or Equivalent.

SUGGESTED INSULATED MOUNTING ARRANGEMENT

In the United Kingdom, Europe, Middle East, and Africa, mounting-hardware policy may differ; check the availability of all items shown with your RCA sales representative or supplier.

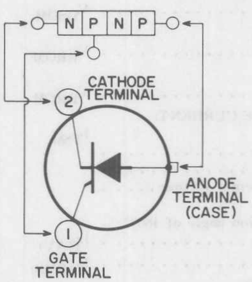
DIMENSIONAL OUTLINE JEDEC No. TO-3



Dimensions in Inches

NOTE: THESE DIMENSIONS SHOULD BE MEASURED AT POINTS .050 TO .055 BELOW SEATING PLANE. WHEN GAUGE IS NOT USED, MEASUREMENT WILL BE MADE AT SEATING PLANE.

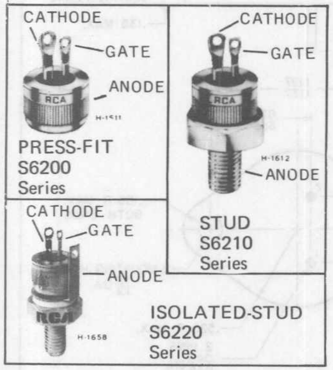
TERMINAL DIAGRAM



PIN 1: GATE

PIN 2: CATHODE

CASE: ANODE



20-Ampere Silicon Controlled Rectifiers

Press-Fit, Stud, and Isolated-Stud Packages

For Low-Voltage Operation – S6200A (40749)*, S6210A (40753)*, S6220A (40757)*
For 120-V Line Operation – S6200B (40750)*, S6210B (40754)*, S6220B (40758)*
For 240-V Line Operation – S6200D (40751)*, S6210D (40755)*, S6220D (40759)*
For High-Voltage Operation – S6200M (40752)*, S6210M (40756)*, S6220M (40760)*

*Numbers in parentheses (e.g. 40749) are former RCA type numbers.

These RCA types are all-diffused, silicon controlled rectifiers (reverse-blocking triode thyristors) designed for power switching and voltage regulator applications and for heating, lighting and motor speed-control circuits.

These SCRs have an RMS on-state current rating ($I_{T\,[RMS]}$) of 20 A and have voltage ratings (V_{DROM}) of 100, 200, 400, and 600 volts.

Features:
- Low switching losses
- High di/dt and dv/dt capabilities
- Shorted-emitter gate-cathode construction
- Forward and reverse gate dissipation ratings
- All-diffused construction—assures exceptional uniformity and stability of characteristics
- Symmetrical gate-cathode construction—provides uniform current density, rapid electrical conduction, and efficient heat dissipation
- Low leakage currents, both forward and reverse
- Low forward voltage drop at high current levels
- Low thermal resistance

MAXIMUM RATINGS, *Absolute-Maximum Values:*

		S6200A S6210A S6220A	S6200B S6210B S6220B	S6200D S6210D S6220D	S6200M S6210M S6220M	
NON-REPETITIVE PEAK REVERSE VOLTAGE						
Gate Open	V_{RSOM}	100	200	400	600	V
NON-REPETITIVE PEAK FORWARD VOLTAGE						
Gate Open	V_{DSOM}	150	250	500	700	V
REPETITIVE PEAK REVERSE VOLTAGE						
Gate Open	V_{RROM}	100	200	400	600	V
REPETITIVE PEAK OFF-STATE VOLTAGE						
Gate Open	V_{DROM}	100	200	400	600	V
PEAK SURGE (NON-REPETITIVE) ON-STATE CURRENT:						
For one cycle of applied principal voltage	I_{TSM}					
50-Hz, sinusoidal		170				A
60-Hz, sinusoidal		200				A
For more than one full cycle of applied principal voltage		See Fig. 10				
ON-STATE CURRENT:						
For case temperature (T_C) = 75° C, conduction angle of 180°						
Average DC value	$I_{T(AV)}$	12.5				A
RMS value	$I_{T(RMS)}$	20				A
RATE-OF-CHANGE OF ON-STATE CURRENT:						
$V_{DM} = V_{(BO)O}$, I_{GT} = 200 mA, t_r = 0.5 μs (See Fig. 2.)	di/dt	200				A/μs
GATE POWER DISSIPATION:						
PEAK FORWARD (for 10 μs max.)	P_{GM}	40				W
AVERAGE (averaging time = 10 ms, max.)	$P_{G(AV)}$	0.5				W
PEAK REVERSE	P_{RGM}	See Fig. 5				
TEMPERATURE RANGE:						
Storage		-65 to 150				°C
Operating (Case)		-65 to 100				°C
Soldering (10 s max. for terminals)		225				°C

ELECTRICAL CHARACTERISTICS

At Maximum Ratings and at Indicated Case Temperature (T_C) Unless Otherwise Specified

CHARACTERISTIC	SYMBOL	LIMITS – ALL TYPES Min.	Typ.	Max.	UNITS
Instantaneous Forward Breakover Voltage: (Gate open, T_C = 100 °C)					
S6200A, S6210A, S6220A	$v_{(BO)O}$	100	–	–	V
S6200B, S6210B, S6220B		200	–	–	
S6200D, S6210D, S6220D		400	–	–	
S6200M, S6210M, S6220M		600	–	–	
Peak Off-State Current: (Gate open, T_C = 100 °C)					
Forward, $V_{DO} = V_{DROM}$	I_{DOM}	–	0.2	3	mA
Reverse, $V_{RO} = V_{RROM}$	I_{RROM}	–	0.1	2	
Instantaneous On-State Voltage: For i_T = 100 A, T_C = 25 °C	v_T	–	1.9	2.4	V
DC Gate Trigger Current: V_D = 12 V (DC), R_L = 30Ω, T_C = 25 °C	I_{GT}	–	8	15	mA
At other case temperatures			See Fig. 11		
DC Gate Trigger Voltage: V_D = 12 V (DC), R_L = 30Ω, T_C = 25 °C	V_{GT}		1.1	2	V
At other case temperatures			See Fig. 12		
Instantaneous Holding Current: Gate open, T_C = 25 °C	i_{HO}		9	20	mA
At other case temperatures			See Fig. 15		
Critical Rate-of-Rise of Off-State Voltage: ($V_{DO} = v_{(BO)O}$ Min. value, Exponential rise, T_C = 100°C, See Fig 5)	dv/dt				V/μs
S6200A, S6200D, S6210A, S6210D, S6220A, S6220D		10	100	–	
S6200B, S6210B, S6220B		10	150	–	
S6200M, S6210M, S6220M		10	75	–	
Gate Controlled Turn-On Time: $V_D = v_{(BO)O}$ Min. value, i_T = 30 A, I_{GT} = 200 mA, 0.1 μs rise time, T_C = 25°C See Fig. 9	t_{gt}	–	2	–	μs
Circuit Commutated Turn-Off Time: $V_D = V_{F(BO)O}$ Min. value, i_T = 18 A, Pulse Duration = 50 μs, **dv/dt = 20 V/μs, di/dt = −30 A/μs, T_C = 75°C** See Fig. 4	t_q	–	29	40	μs
Thermal Resistance:					
Junction-to-Case	$R_{\theta JC}$	–	–	1.2	°C/W
Junction-to-Isolated Stud	$R_{\theta JIS}$	–	–	1.4	

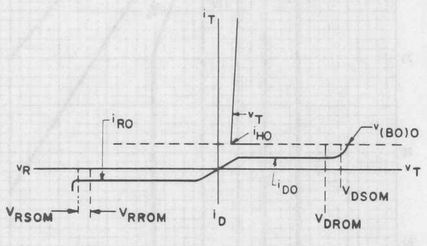


Fig. 1—Principal voltage-current characteristic.

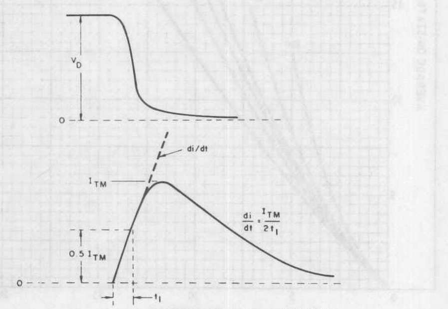


Fig. 2—Rate of change of on-state current with time (defining di/dt).

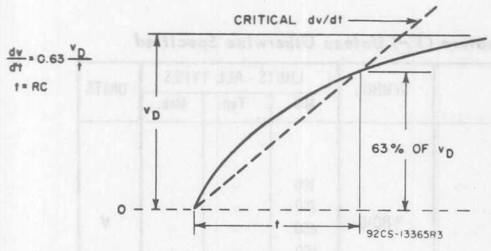


Fig. 3—Rate of rise of off-state voltage with time (defining dv/dt).

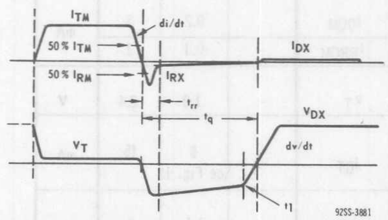


Fig. 4—Relationship between on-state current, reverse current, on-state voltage, and off-state voltage showing reference points for definition of turn-off time (t_q).

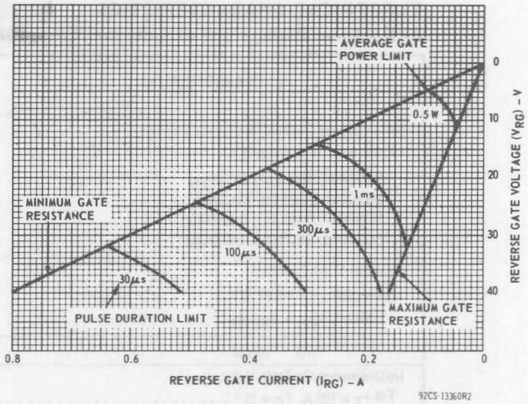


Fig. 5—Reverse gate voltage vs. reverse gate current.

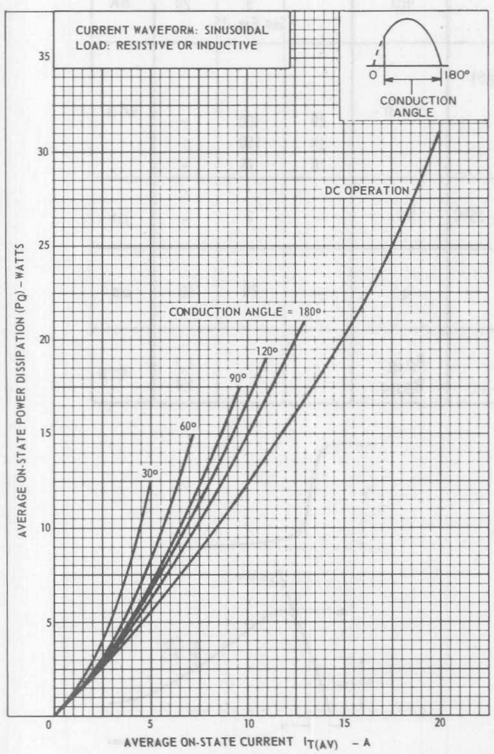


Fig. 6—Power dissipation vs. on-state current.

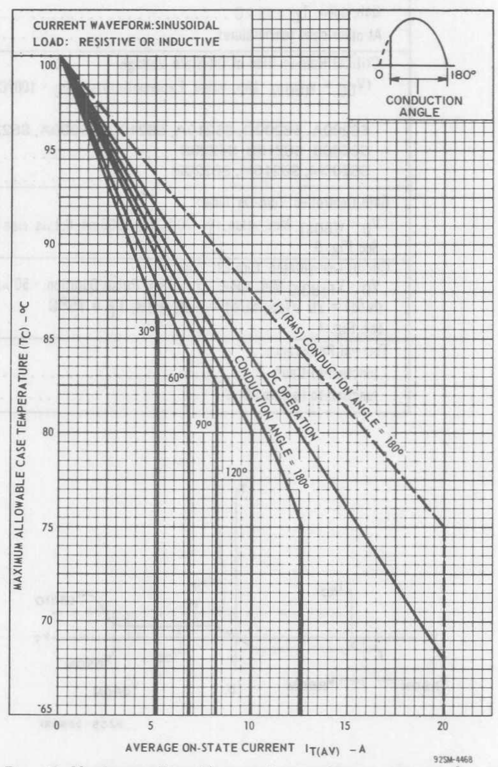


Fig. 7—Maximum allowable case temperature vs. average forward current for stud and press-fit.

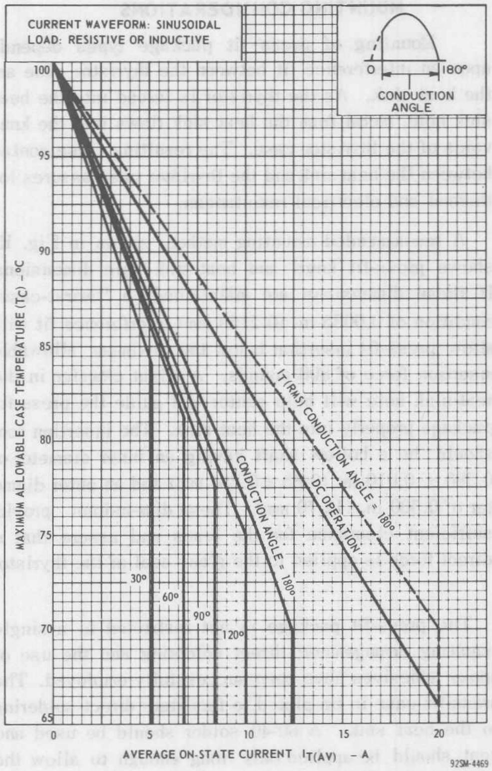


Fig. 8—Maximum allowable case temperature vs. average forward current for isolated stud.

Fig. 9—Gate controlled turn-on time (t_{gt}) vs. gate-trigger current.

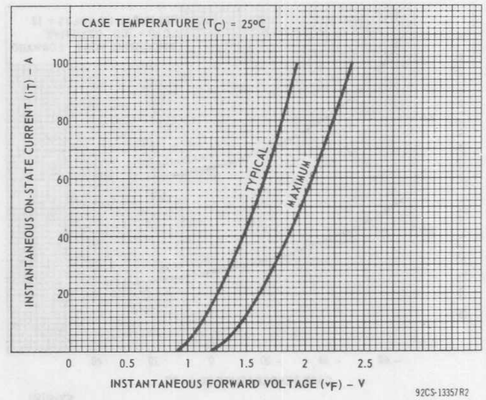


Fig. 10—Instantaneous on-state current vs. on-state voltage.

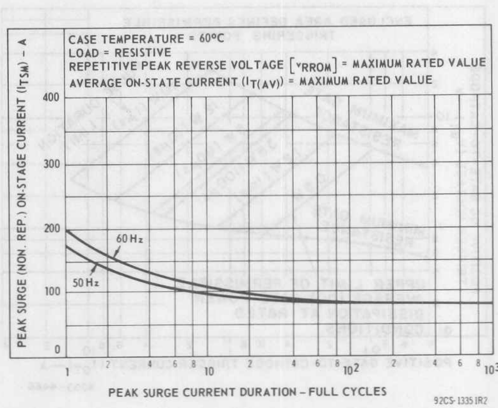


Fig. 11—Peak surge on-state current vs. surge current duration.

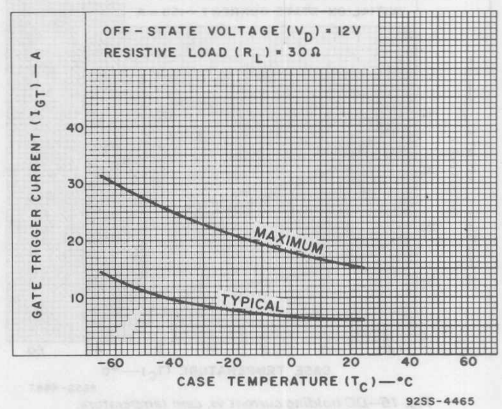


Fig. 12—DC gate-trigger current (forward) vs. case temperature.

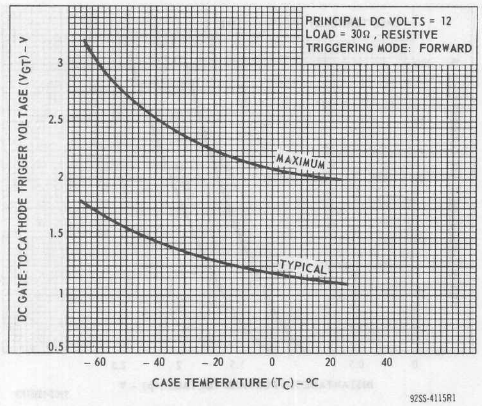


Fig. 13—DC gate-trigger voltage vs. case temperature.

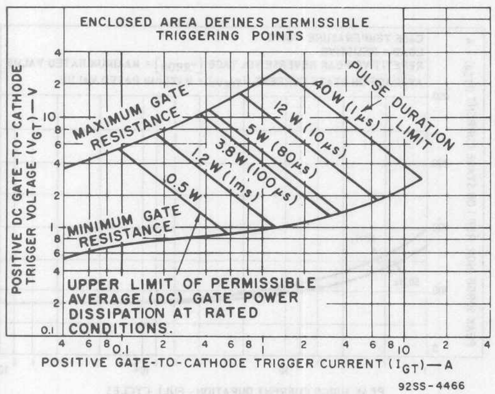


Fig. 14—Typical forward-biased gate trigger characteristics.

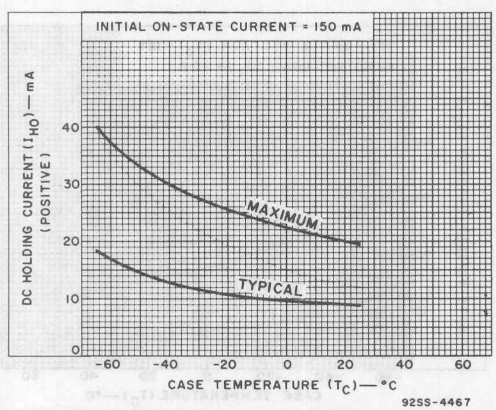


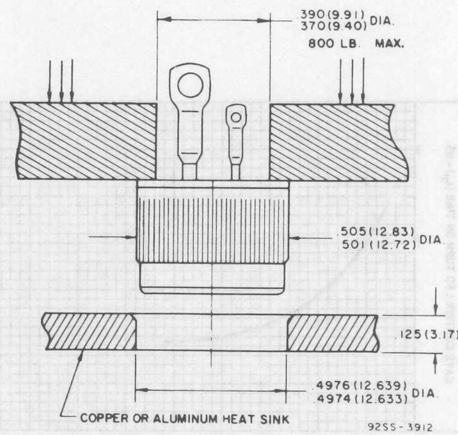
Fig. 15—DC holding current vs. case temperature.

MOUNTING CONSIDERATIONS

Mounting of press-fit package types depends upon an interference fit between the thyristor case and the heat sink. As the thyristor is forced into the heat-sink hole, metal from the heat sink flows into the knurl voids of the thyristor case. The resulting close contact between the heat sink and the thyristor case assures low thermal and electrical resistances.

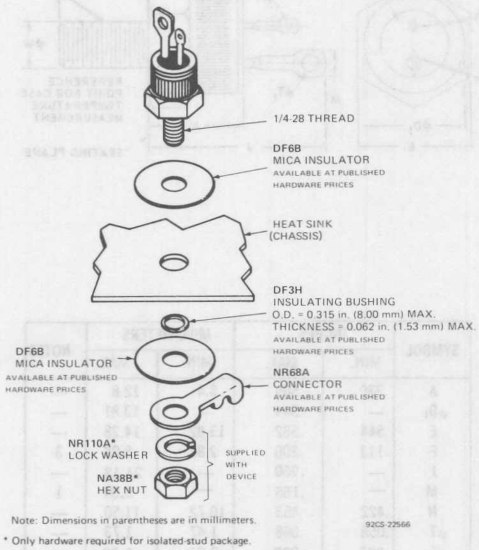
A recommended mounting method, shown in Fig. 15, shows press-fit knurl and heat-sink hole dimensions. If these dimensions are maintained, a "worst-case" condition of 0.0085 in. (0.2159 mm) interference fit will allow press-fit insertion below the maximum allowable insertion force of 800 pounds. A slight chamfer in the heat-sink hole will help center and guide the press-fit package properly into the heat sink. The insertion tool should be a hollow shaft having an inner diameter of 0.380 ± 0.010 in. (9.65 ± 0.254 mm) and an outer diameter of 0.500 in. (12.70 mm). These dimensions provide sufficient clearance for the leads and assure that no direct force is applied to the glass seal of the thyristor.

The press-fit package is not restricted to a single mounting arrangement; direct soldering and the use of epoxy adhesives have been successfully employed. The press-fit case is tin-plated to facilitate direct soldering to the heat sink. A 60-40 solder should be used and heat should be applied only long enough to allow the solder to flow freely.



NOTE: Dimensions in parentheses are in millimeters and are derived from the basic inch dimensions as indicated.

Fig. 16—Suggested mounting method for press-fit package types.



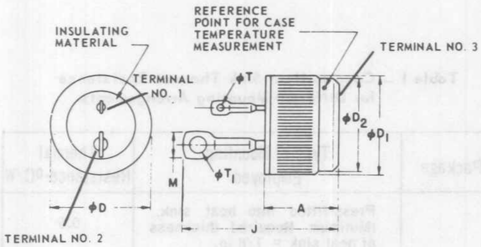
In the United Kingdom, Europe, Middle East, and Africa, mounting-hardware policies may differ; check the availability of all items shown with your RCA sales representative or supplier.

Fig. 17—Suggested mounting arrangement for stud and isolated-stud package types.

Table I – Case-to-Heat Sink Thermal Resistance for Different Mounting Arrangements.

Package	Type of Mounting Employed	Thermal Resistance-°C/W
Press-Fit	Press-fitted into heat sink. (Minimum Required thickness of heat sink = 1/8 in.	0.5
	Soldered directly to heat sink. (60-40 solder which has a melting point of 188° C should be used. Heating time should be sufficient to cause solder to flow freely).	0.1 to 0.35
Stud	Directly mounted on heat sink with or without the use of heat-sink compound.	0.6
	Mounted on heat sink with a 0.004 to 0.006 in. thick mica insulating washer used between unit and heat sink.	
	Without heat sink compound	2.5
	With heat sink compound	1.5

DIMENSIONAL OUTLINE FOR S6200 SERIES



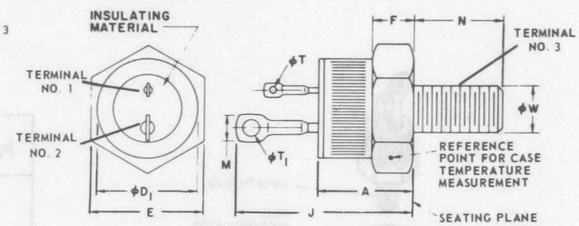
SYMBOL	INCHES		MILLIMETERS		NOTES
	MIN.	MAX.	MIN.	MAX.	
A	—	.380	—	9.65	
φD	.501	.510	12.73	12.95	
φD₁	—	.505	—	12.83	2
φD₂	.465	.475	11.81	12.07	
J	—	.750		19.05	
M	—	.155	—	3.94	1
φT	.058	.068	1.47	1.73	
φT₁	.080	.090	2.03	2.29	

NOTE 1: Contour and angular orientation of these terminals is optional.

NOTE 2: Outer diameter of knurled surface.

92SS-3816

DIMENSIONAL OUTLINE FOR S6210 SERIES



SYMBOL	INCHES		MILLIMETERS		NOTES
	MIN.	MAX.	MIN.	MAX.	
A	.330	.505	8.4	12.8	—
φD₁	—	.544	—	13.81	—
E	.544	.562	13.82	14.28	—
F	.113	.200	2.87	5.08	3
J	—	.950	—	24.13	—
M	—	.155	—	3.94	1
N	.422	.453	10.72	11.50	—
φT	.058	.068	1.47	1.73	—
φT₁	.080	.090	2.03	2.29	—
φW	.2225	.2268	5.652	5.760	2

NOTE 1: Contour and angular orientation of these terminals is optional.

NOTE 2: Pitch diameter of ¼-28 UNF-2A (coated) threads (ASA B1. 1-1960).

NOTE 3: A chamfer or undercut on one or both ends of hexagonal portion is optional.

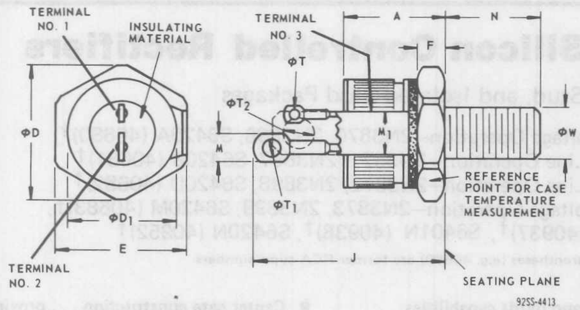
92SS-3817

TERMINAL CONNECTIONS

For S6200 and S6210 Series

Terminal No. 1 – Gate
Terminal No. 2 – Cathode
Case, Terminal No. 3 – Anode

DIMENSIONAL OUTLINE FOR S6220 SERIES



SYMBOL	INCHES		MILLIMETERS		NOTES
	MIN.	MAX.	MIN.	MAX.	
A	–	.673	–	17.09	
ΦD	.604	.614	15.34	15.59	
ΦD1	.501	.505	12.72	12.82	
E	.551	.557	13.99	14.14	
F	.175	.185	4.44	4.69	
J	–	1.055	–	26.79	
M	–	.155	–	3.94	
M1	.200	.210	5.08	5.33	
N	.422	.452	10.72	11.48	
ΦT	.058	.068	1.47	1.73	2
ΦT1	.080	.090	2.03	2.29	2
ΦT2	.138	.148	3.50	3.75	2
ΦW	.2225	.2268	5.652	5.760	3

NOTE 1: Ceramic between hex (stud) and terminal No. 3 is beryllium oxide.

NOTE 2: Contour and angular orientation of these terminals is optional.

NOTE 3: Pitch diameter of ¼-28 UNF-2A (coated) threads (ASA B1. 1-1960).

"WARNING: The S6220 series should be handled with care. The ceramic portion of these thyristors contains BERYLLIUM OXIDE as a major ingredient. Do not crush, grind, or abrade these portions of the thyristors because the dust resulting from such action may be hazardous if inhaled."

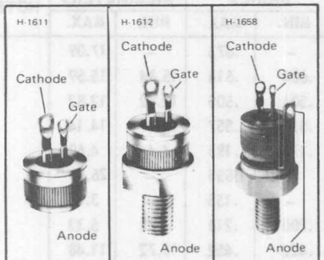
TERMINAL CONNECTIONS

For S6220 Series

Terminal No. 1 – Gate
Terminal No. 2 – Cathode
Terminal No. 3 – Anode

RCA
Solid State Division

Thyristors
2N3870-2N3873,S6400N 2N3896-2N3899,S6410N S6420A,B,D,M,N



Press-fit	Stud	Isolated-stud
2N3870	2N3896	S6420A
2N3871	2N3897	S6420B
2N3872	2N3898	S6420D
2N3873	2N3899	S6420M
S6400N	S6410N	S6420N

35-A Silicon Controlled Rectifiers

Press-Fit, Stud, and Isolated-Stud Packages

For Low-Voltage Operation—2N3870, 2N3896, S6420A (40680)†
For 120-V Line Operation—2N3871, 2N3897, S6420B (40681)†
For 240-V Line Operation—2N3872, 2N3898, S6420D (40682)†
For High-Voltage Operation—2N3873, 2N3899, S6420M (40683)†, S6400N (40937)†, S6401N (40938)†, S6420N (40952)†

† Numbers in parentheses (e.g. 40680) are former RCA type numbers.

Features:

- **High di/dt and dv/dt capabilities**
- **Low on-state voltage at high current levels**
- **Low thermal resistance**
- **Shorted-emitter gate-cathode construction . . . contains an internally diffused resistor between gate and cathode**
- **Center gate construction . . . provides rapid uniform gate-current spreading for faster turn-on with substantially reduced heating effects**

These RCA types are all-diffused, silicon controlled rectifiers (reverse-blocking triode thyristors) designed for power switching, power control, and voltage regulator applications and for heating, lighting, and motor speed-control circuits.

MAXIMUM RATINGS, *Absolute-Maximum Values:*		2N3870 2N3896 S6420A	2N3871 2N3897 S6420B	2N3872 2N3898 S6420D	2N3873 2N3899 S6420M	S6400N S6410N S6420N	
***NON-REPETITIVE PEAK REVERSE VOLTAGE▲**							
Gate Open	V_{RSOM}	150	330	660	700	900	V
NON-REPETITIVE PEAK OFF-STATE VOLTAGE▲							
Gate Open	V_{DSOM}	150	330	660	700	900	V
***REPETITIVE PEAK REVERSE VOLTAGE▲**							
Gate Open	V_{RROM}	100	200	400	600	800	V
***REPETITIVE PEAK OFF-STATE VOLTAGE▲**							
Gate Open	V_{DROM}	100	200	400	600	800	V
ON-STATE CURRENT:							
T_C = 65°C◆, conduction angle = 180°:							
RMS	$I_{T(RMS)}$			35			A
* Average	$I_{T(AV)}$			22			A
For other conditions				See Figs. 3 & 5			
PEAK SURGE (NON-REPETITIVE) ON-STATE CURRENT:	I_{TSM}						
For one full cycle of applied principal voltage							
* 60 Hz (sinusoidal)				350			A
50 Hz (sinusoidal)				300			A
For more than one full cycle of applied principal voltage				See Fig. 5			
RATE OF CHANGE OF ON-STATE CURRENT							
$V_D = V_{DROM}$, I_{GT} = 200 mA, t_r = 0.5 μs (See Fig. 13)	di/dt			200			A/μs
FUSING CURRENT (for SCR protection):							
T_J = -40 to 100°C, t = 1 to 8.3 ms	I^2t			300			A^2s
GATE POWER DISSIPATION●:							
Peak Forward (for 10 μs max., See Fig. 8)	P_{GM}			40			W
Peak Reverse	P_{RGM}			See Fig. 9			
Average (averaging time = 10 ms max.)	$P_{G(AV)}$			0.5			W
***TEMPERATURE RANGE■:**							
Storage				-40 to 125			°C
Operating (Case)				-40 to 100			°C
TERMINAL TEMPERATURE (During soldering):	T_T						
For 10 s max. (terminals and case)				225			°C

* In accordance with JEDEC registration data filed for the JEDEC (2N-series) types.
▲ These values do not apply if there is a positive gate signal. Gate must be open or negatively biased.
◆ T_C = 60° for isolated-stud package types.
● Any product of gate current and gate voltage which results in a gate power less than the maximum is permitted.
■ Temperature measurement point is shown on the DIMENSIONAL OUTLINE.

11-73

ELECTRICAL CHARACTERISTICS

At Maximum Ratings Unless Otherwise Specified and at Indicated Case Temperature (T_C)

CHARACTERISTIC	SYMBOL	LIMITS FOR ALL TYPES Unless Otherwise Specified MIN.	TYP.	MAX.	UNITS
Peak Off-State Current: (Gate open, T_C = 100°C) Forward Current (I_{DOM}) at $V_D = V_{DROM}$ Reverse Current (I_{ROM}) at $V_R = V_{RROM}$	I_{DOM} or I_{ROM}				mA
2N3870, 2N3896, S6420A		–	0.2	2*	
2N3871, 2N3897, S6420B		–	0.25	2.5*	
2N3872, 2N3898, S6420D		–	0.3	3*	
2N3873, 2N3899, S6420M, S6400N, S6410N, S6420N		–	0.35	4*	
Instantaneous On-State Voltage:	v_T				V
i_T = 69 A (peak), T_C = 25°C		–	–	1.85*	
i_T = 100 A (peak), T_C = 25°C		–	1.7	2.1	
DC Gate Trigger Voltage:	V_{GT}				V
V_D = 12 V (dc), R_L = 30 Ω, T_C = -40°C		–	1.5	3*	
V_D = 12 V (dc), R_L = 30 Ω, T_C = 25°C		–	1.1	2	
For other case temperatures			See Fig. 11		
DC Gate Trigger Current:	I_{GT}				mA
V_D = 12 V (dc), R_L = 30 Ω, T_C = -40°C		–	46	80*	
V_D = 12 V (dc), R_L = 30 Ω, T_C = 25°C		1	25	40	
For other case temperatures			See Fig. 10		
Instantaneous Holding Current: Gate open,	i_{HO}				mA
T_C = 25°C		0.5	30	70	
For other case temperatures			See Fig. 7		
Gate Controlled Turn-On Time: (Delay Time + Rise Time) For $V_D = V_{DROM}$, I_{GT} = 200 mA, t_r = 0.1 μs, I_T = 30 A (peak), T_C = 25°C (See Fig. 12 & 14.)	t_{gt}	–	1.25	2	μs
Circuit Commutated Turn-Off Time: $V_D = V_{DROM}$, i_T = 18 A, pulse duration = 50 μs, dv/dt = 20 V/μs, -di/dt = -30 A/μs, I_{GT} = 200 mA, T_C = 80°C (See Fig. 15.)	t_q	–	20	40	μs
Critical Rate of Rise of Off-State Voltage: $V_D = V_{DROM}$, exponential voltage rise, Gate open, T_C = 100°C (See Fig. 16.)	dv/dt	10	100	–	V/μs
Thermal Resistance, Junction-to-Case: Steady-State	$R_{\theta JC}$				°C/W
Press-fit & stud types		–	–	0.9*	
Isolated-stud types		–	–	1	

*In accordance with JEDEC registration data filed for the JEDEC (2N-series) types.

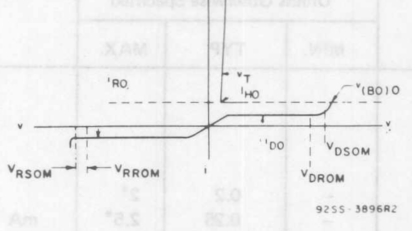


Fig.1—Principal voltage-current characteristic.

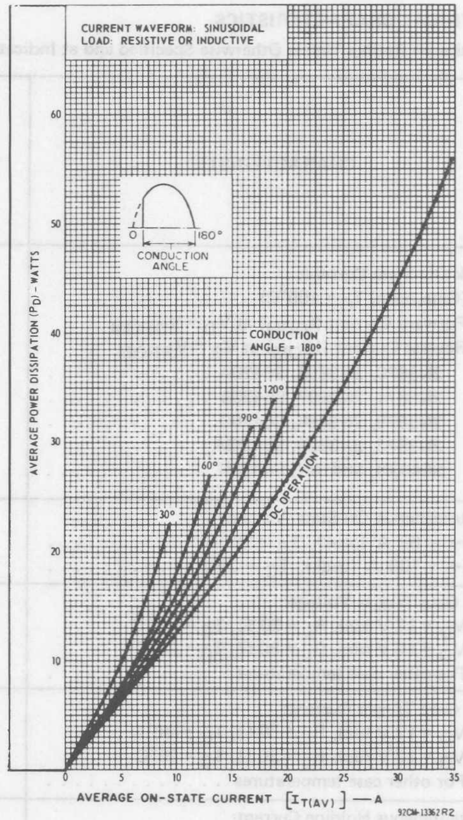


Fig.2—Power dissipation vs. on-state current.

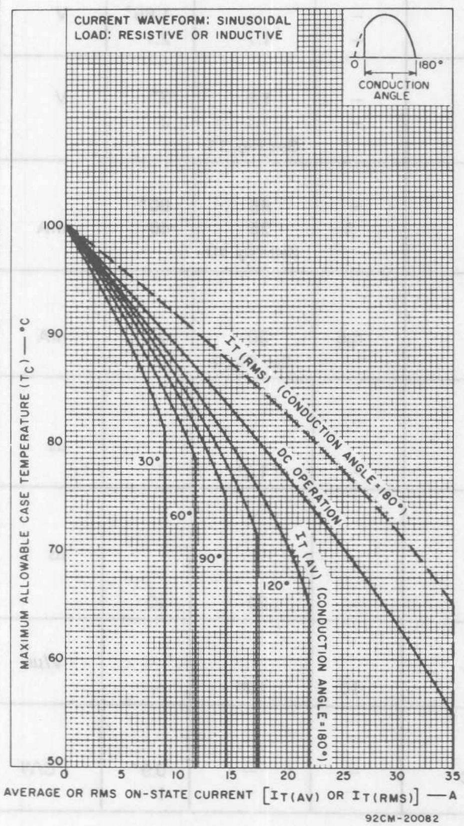


Fig.3—Maximum allowable case temperature vs. on-state current for press-fit and stud types.

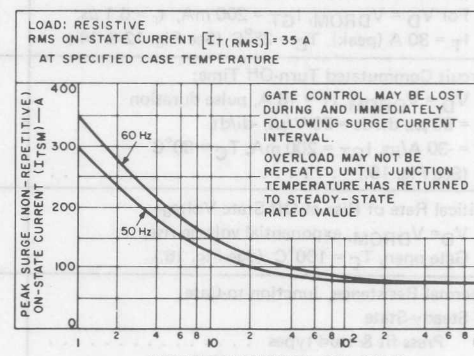


Fig.4 —Peak surge on-state current vs. surge current duration.

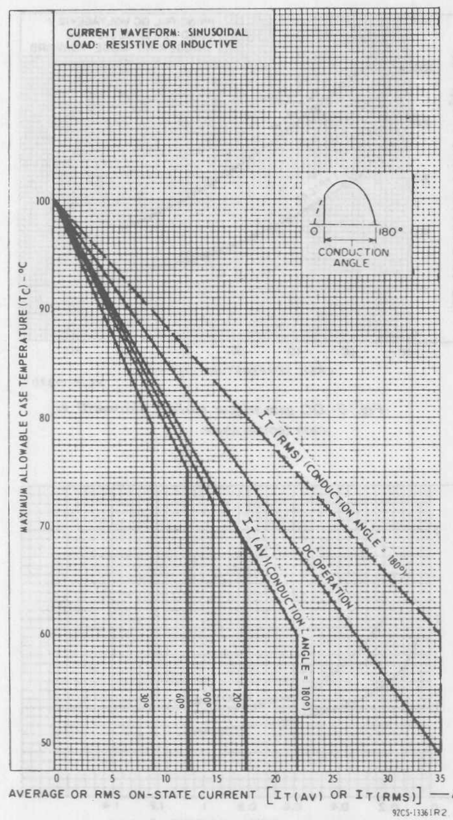


Fig.5 – Maximum allowable case temperature vs. on-state current for isolated-stud types.

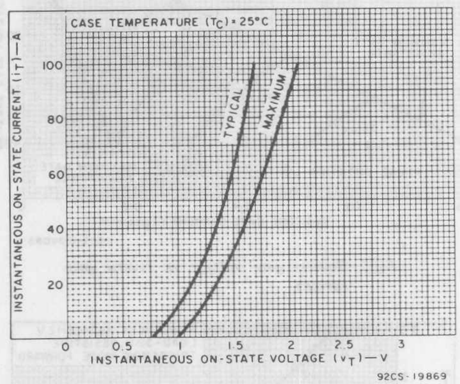


Fig.6 – Instantaneous on-state current vs. on-state voltage.

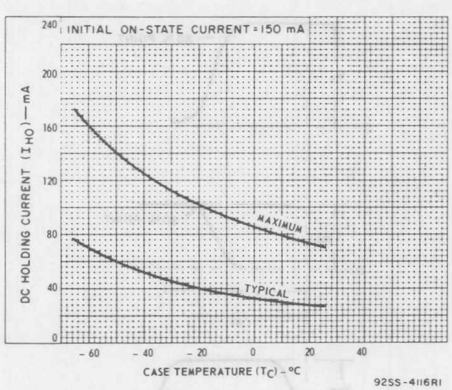


Fig.7 – DC holding current vs. case temperature.

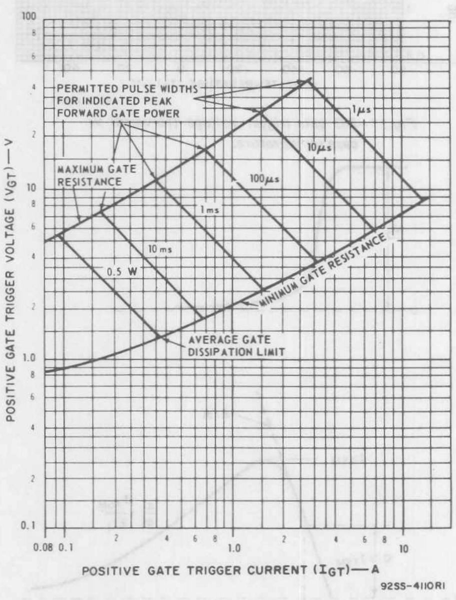


Fig.8 – Gate pulse characteristics for forward triggering mode.

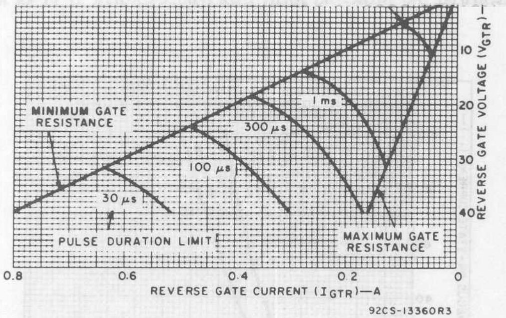


Fig.9—Reverse gate voltage vs. reverse gate current.

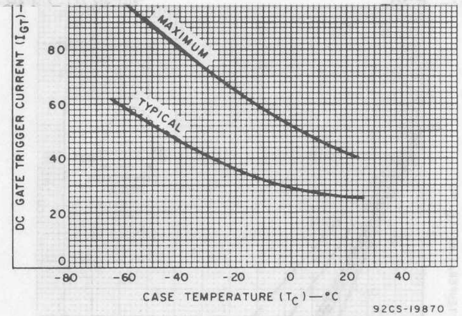


Fig.10—DC gate trigger current (forward) vs. case temperature.

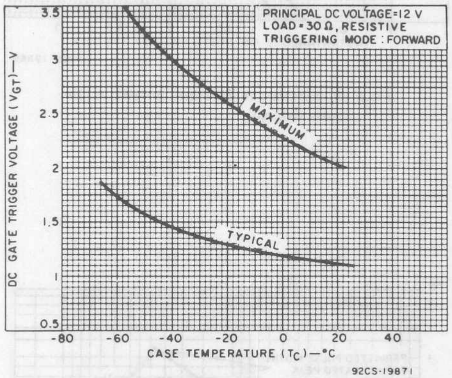


Fig.11—DC gate trigger voltage (forward) vs. case temperature.

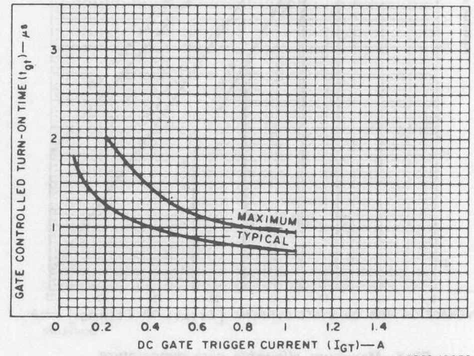


Fig.12—Gate-controlled turn-on time vs. gate trigger current.

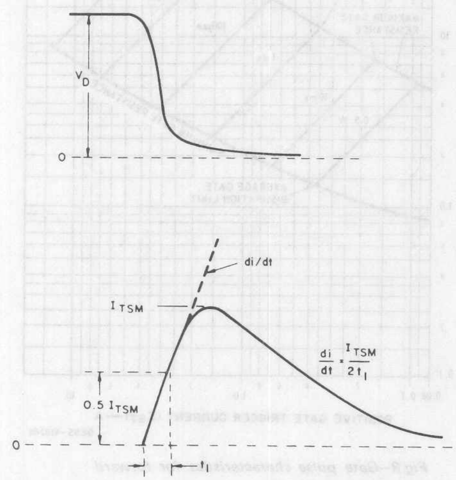


Fig.13—Rate of change of on-state current with time (defining di/dt).

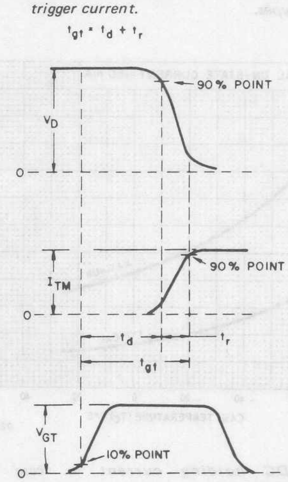


Fig.14—Relationship between off-state voltage, on-state current, and gate trigger voltage showing reference points for definition of turn-on time (t_{gt}).

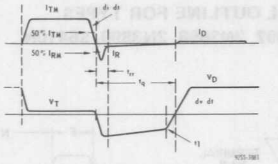


Fig.15—Relationship between instantaneous on-state current and voltage showing reference points for definition of circuit commutated turn-off time (t_q).

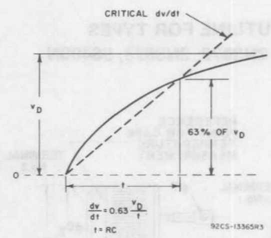


Fig.16– Rate of rise of off-stage voltage with time (defining critical dv/dt).

MOUNTING CONSIDERATIONS

Mounting of press-fit package types depends upon an interference fit between the thyristor case and the heat sink. As the thyristor is forced into the heat-sink hole, metal from the heat sink flows into the knurl voids of the thyristor case. The resulting close contact between the heat sink and the thyristor case assures low thermal and electrical resistances.

A recommended mounting method, shown in Fig. 17, shows press-fit knurl and heat-sink hole dimensions. If these dimensions are maintained, a "worst-case" condition of 0.0085 in. (0.2159 mm) interference fit will allow press-fit insertion below the maximum allowable insertion force of 800 pounds. A slight chamfer in the heat-sink hole will help center and guide the press-fit package properly into the heat sink. The insertion tool should be a hollow shaft having an inner diameter of 0.380 ± 0.010 in. (9.65 ± 0.254 mm) and an outer diameter of 0.500 in. (12.70 mm). These dimensions provide sufficient clearance for the leads and assure that no direct force will be applied to the glass seal of the thyristor.

The press-fit package is not restricted to a single mounting arrangement; direct soldering and the use of epoxy adhesives have been successfully employed. The press-fit case is tin-plated to facilitate direct soldering to the heat sink. A 60-40 solder should be used and heat should be applied only long enough to allow the solder to flow freely.

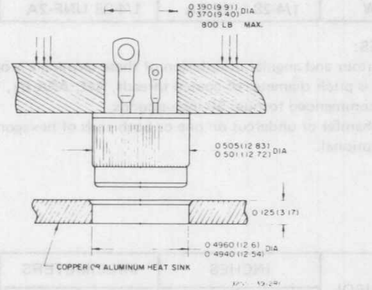
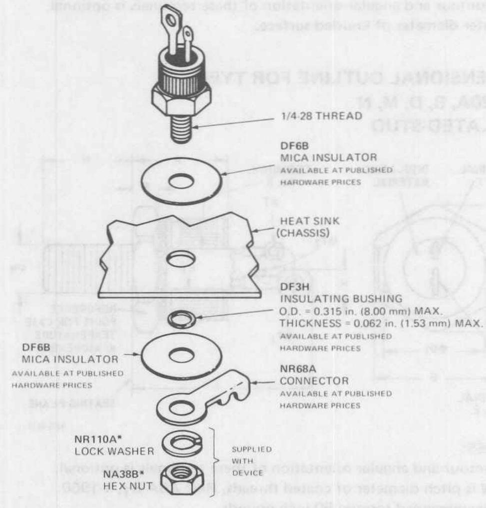


Fig.17—Suggested mounting method for press-fit package types.

Table I—Case-to-Heat Sink Thermal Resistance for Different Mounting Arrangements.

PACKAGE	TYPE OF MOUNTING EMPLOYED	THERMAL RESISTANCE-°C/W
Press-Fit	Press-fitted into heat sink. (Minimum required thickness of heat sink = 1/8 in. (3.17 mm)	0.5
	Soldered directly to heat sink. (60-40 solder which has a melting point of 188°C should be used. Heating time should be sufficient to cause solder to flow freely).	0.1 to 0.35
Stud	Directly mounted on heat sink with or without the use of heat-sink compound.	0.6

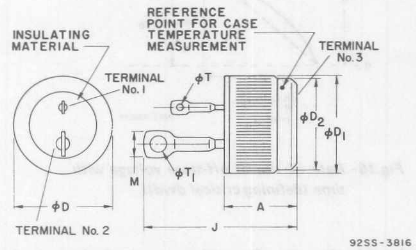


Note: Dimensions in parentheses are in millimeters.
92CS-22566
* Only hardware required for isolated-stud package.

In the United Kingdom, Europe, Middle East, and Africa, mounting-hardware policies may differ; check the availability of all items shown with your RCA sales representative or supplier.

Fig.18—Suggested mounting arrangement for stud and isolated-stud package types.

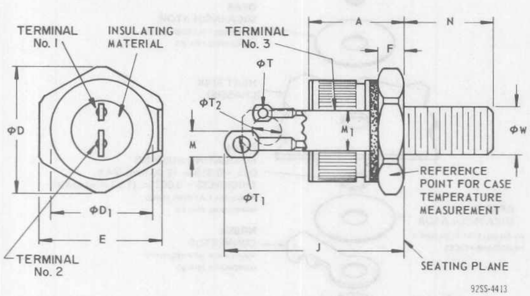
DIMENSIONAL OUTLINE FOR TYPES
2N3870, 2N3871, 2N3872, 2N3873, S6400N
PRESS-FIT



SYMBOL	INCHES		MILLIMETERS		NOTES
	MIN.	MAX.	MIN.	MAX.	
A	–	0.380	–	9.65	
ϕD	0.501	0.510	12.73	12.95	
ϕD_1	–	0.505	–	12.83	2
ϕD_2	0.465	0.475	11.81	12.07	
J	–	0.750	–	19.05	
M	–	0.155	–	3.94	1
ϕT	0.058	0.068	1.47	1.73	
ϕT_1	0.080	0.090	2.03	2.29	

NOTES:
1. Countour and angular orientation of these terminals is optional.
2. Outer diameter of knurled surface.

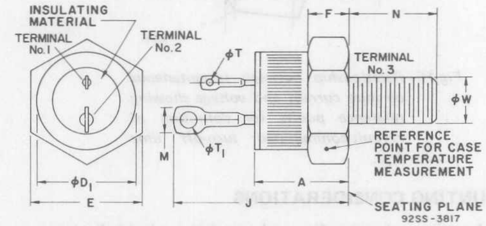
DIMENSIONAL OUTLINE FOR TYPES
S6420A, B, D, M, N
ISOLATED-STUD



NOTES:
1. Contour and angular orientation of these terminals is optional.
2. ϕW is pitch diameter of coated threads, Ref: ASA B_1, 1-1960. Recommended torque: 50 inch-pounds.
3. A chamfer or undercut on one or both ends of hexagonal portion is optional.
4. Isolating material (ceramic) between hex (stud) and terminal No. 3 is beryllium oxide.

TERMINAL CONNECTIONS FOR ALL TYPES
No. 1 – Gate
No. 2 – Cathode
Case, No. 3 – Anode

DIMENSIONAL OUTLINE FOR TYPES
2N3896, 2N3897, 2N3898, 2N3899, S6410N
STUD



SYMBOL	INCHES		MILLIMETERS		NOTES
	MIN.	MAX.	MIN.	MAX.	
A	0.330	0.505	8.4	12.8	
ϕD_1	–	0.544	–	13.81	
E	0.544	0.562	13.82	14.28	
F	0.113	0.200	2.87	5.08	3
J	–	0.950	–	24.13	
M	–	0.155	–	3.94	1
N	0.422	0.453	10.72	11.50	
ϕT	0.058	0.068	1.47	1.73	
ϕT_1	0.080	0.090	2.03	2.29	
ϕW	1/4-28 UNF-2A		1/4-28 UNF-2A		2

NOTES:
1. Contour and angular orientation of these terminals is optional.
2. ϕW is pitch diameter of coated threads, Ref: ASA B_1, 1-1960. Recommended torque: 50 inch-pounds.
3. A chamfer or undercut on one or both ends of hexagonal portion is optional.

SYMBOL	INCHES		MILLIMETERS		NOTES
	MIN.	MAX.	MIN.	MAX.	
A	–	0.673	–	17.09	
ϕD	0.604	0.614	15.34	15.59	
ϕD_1	0.501	0.505	12.72	12.82	
E	0.551	0.557	13.99	14.14	
F	0.175	0.185	4.44	4.69	3
J		1.055		26.79	
M	–	0.155	–	3.94	1
M_1	0.200	0.210	5.08	5.33	1
N	0.422	0.452	10.72	11.48	
ϕT	0.058	0.068	1.47	1.73	
ϕT_1	0.080	0.090	2.03	2.29	
ϕT_2	0.138	0.148	3.50	3.75	
ϕW	1/4-28 UNF-2A		1/4-28 UNF-2A		2

WARNING: The ceramic of the isolated-stud package contains beryllium oxide. Do not crush, grind, or abrade this part because the dust resulting from such action may be hazardous if inhaled. Disposal should be by burial.

RCA
Solid State Division

Thyristors

2N681-2N690

All-Diffused Types for Power-Control and Power-Switching Applications

JEDEC TO-48

RCA-2N681 through 2N690 controlled-rectifiers are all-diffused, three-junction, silicon devices for use in power-control and power-switching applications requiring blocking-voltage capabilities to 600 volts and forward-current capability of 16 amperes (average value) or 25 amperes (rms value).

FEATURES

- All-diffused construction – assures exceptional uniformity and stability of characteristics
- Multi-diffusion process – permits precise control of individual junction parameters
- Symmetrical gate-cathode construction – provides uniform current density, rapid electrical conduction, and efficient heat dissipation
- Direct-soldered internal construction – assures exceptional resistance to fatigue
- Each unit aged at maximum ratings to assure dependable performance
- All-welded construction and hermetic sealing
- Shorted emitter gate-cathode construction
- Low leakage currents, both forward and reverse
- Low forward voltage drop at high current levels
- Low thermal resistance
- Exceptionally high stud-torque capability through use of high-strength copper-alloy stud

Absolute-Maximum Ratings, for Operation with Sinusoidal AC Supply Voltage at a Frequency between 50 and 400 cps, and with Resistive or Inductive Load

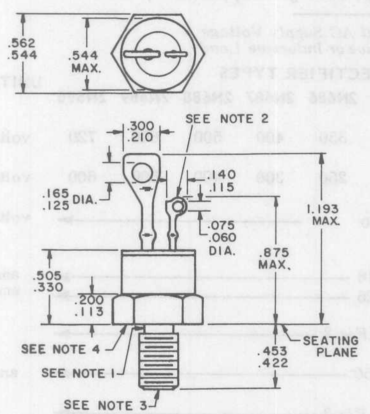
RATINGS	CONTROLLED-RECTIFIER TYPES 2N681	2N682	2N683	2N684	2N685	2N686	2N687	2N688	2N689	2N690	UNITS
Transient Peak Reverse Voltage (Non-Repetitive), v_{RM} (non-rep)[a]	35	75	150	225	300	350	400	500	600	720	volts
Peak Reverse Voltage (Repetitive), v_{RM} (rep)[b]	25	50	100	150	200	250	300	400	500	600	volts
Peak Forward Blocking Voltage (Repetitive), v_{FBOM} (rep)[c]					← 600 →						volts
Forward Current:											
For case temperature (T_C) of +65° C, and a conduction angle of 180°, I_{FAV}[d]					← 16 →						amp
RMS value, I_{FRMS}[e]					← 25 →						amp
For other case temperatures and conduction angles					← See *Fig.2* →						
Peak Surge Current, i_{FM} (surge)[f]:											
For one cycle of applied voltage					← 150 →						amp
For more than one cycle of applied voltage					← See *Fig.3* →						
Peak Gate Power, P_{GM}[g]					← 5 →						watts
Average Forward Gate Power, P_{GAV}[h]					← 0.5 →						watt
Peak Forward Gate Current, i_{GKM}[i]					← 2 →						amp
Peak Gate Voltage:											
Forward, v_{GKM}[k]					← 10 →						volts
Reverse, v_{KGM}[k]					← 5 →						volts
Temperature:											
Storage, T_{stg}					← -65 to +150 →						°C
Operating, Case[#], T_C					← -65 to +125 →						°C
Free Air, T_{FA}					← See *Fig.4* →						

Electrical and Thermal Characteristics at Maximum Electrical Ratings (unless otherwise specified), and at Indicated Case Temperature, T_C.

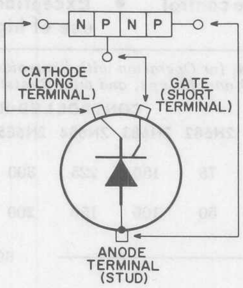
CHARACTERISTICS	2N681	2N682	2N683	2N684	2N685	2N686	2N687	2N688	2N689	2N690	UNITS
	CONTROLLED-RECTIFIER TYPES										
Minimum Forward Breakover Voltage, v_{BOO}[m]:											
At T_C = +125° C	25	50	100	150	200	250	300	400	500	600	volts
Maximum Average (DC) Forward Blocking Current, I_{FBOAV}[n]:											
At T_C = +125° C	6.5	6.5	6.5	6.5	6	5.5	5	4	3	2.5	ma
Maximum Average (DC) Reverse Blocking Current, I_{RBOAV}[p]:											
At T_C = +125° C	6.5	6.5	6.5	6.5	6	5.5	5	4	3	2.5	ma
Maximum Average Forward Voltage Drop, V_{FAV}[q]:											
At a Forward Current of 25 amperes and a T_C = +65° C	←				0.86					→	volt
Maximum DC Gate-Trigger Current, I_{GT}[r]:											
At T_C = +125° C	←				25					→	ma
DC Gate-Trigger Voltage, V_{GT}[s]:											
Maximum at T_C = -65° to +125° C.......	←				3					→	volts
Minimum at T_C = +125° C	←				0.25					→	volt
Holding Current, i_{HOO}[t]:											
Typical at T_C = +125° C	←				15					→	ma
Maximum Thermal Resistance, Junction-to-Case, $\theta_{J\text{-}C}$[u]	←				2					→	°C/watt

[#] Measured at the center of any of the six major faces on the perimeter of the hexagonal flange.

DIMENSIONAL OUTLINE JEDEC TO-48



TERMINAL DIAGRAM

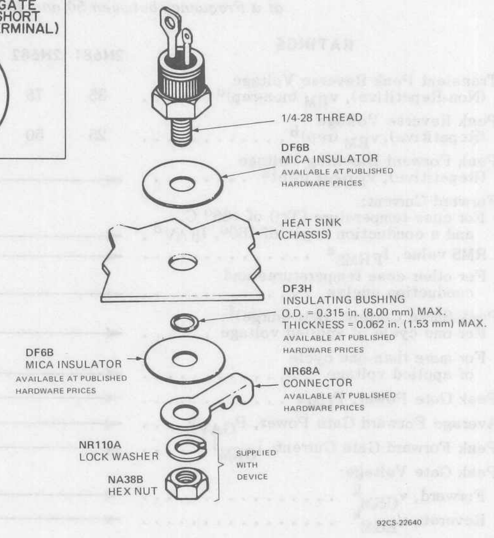


Note 1: Complete threads to extend to within 2-1/2 threads of head. Dia. of unthreaded portion 0.249" maximum, 0.220" minimum.

Note 2: Angular orientation of these terminals is undefined. Square or radius on end of terminal is optional.

Note 3: 1/4-28 UNF-2A. Maximum pitch dia. of plated threads shall be basic pitch dia. 0.2268", minimum pitch dia. 0.2225". Ref. (Screw Thread Standards for Federal Services 1957) Handbook H28 1957 P1.

Note 4: A chamfer (or undercut) on one or both ends of hexagonal portion is optional.



In the United Kingdom, Europe, Middle East, and Africa, mounting-hardware policies may differ; check the availability of all items shown with your RCA sales representative or supplier.

Suggested Mounting Arrangement for Insulating Types 2N681 - 2N690 from Heat Sink.

TYPICAL E-I CHARACTERISTIC OF SILICON CONTROLLED-RECTIFIER

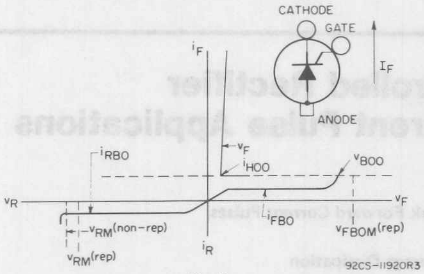


Fig. 1

RATING CHART

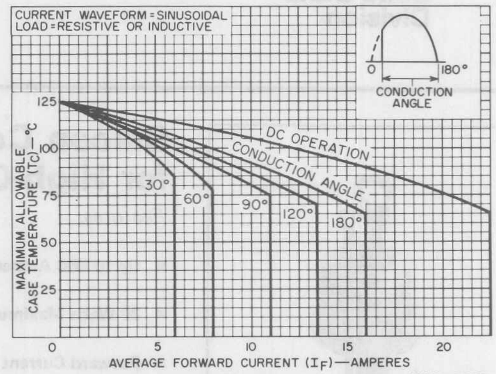


Fig. 2

SURGE CURRENT RATING CHART

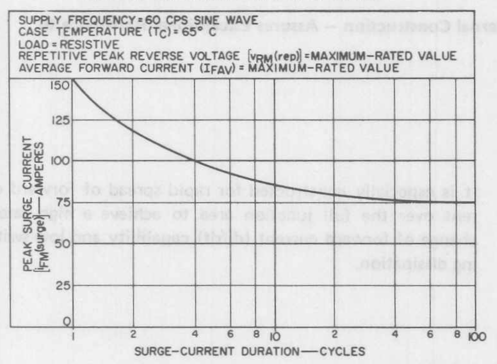


Fig. 3

OPERATION GUIDANCE CHART

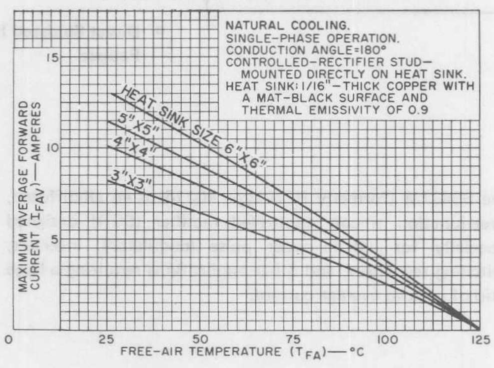


Fig. 4

FORWARD CHARACTERISTICS

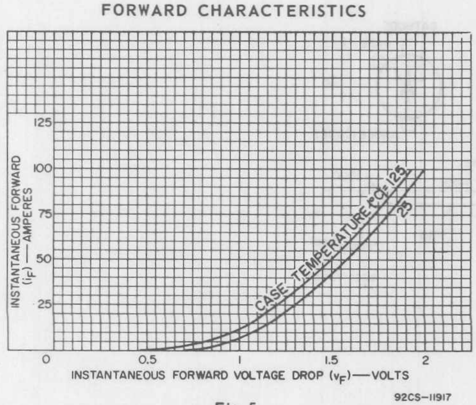


Fig. 5

FORWARD AND REVERSE LEAKAGE CHARACTERISTICS

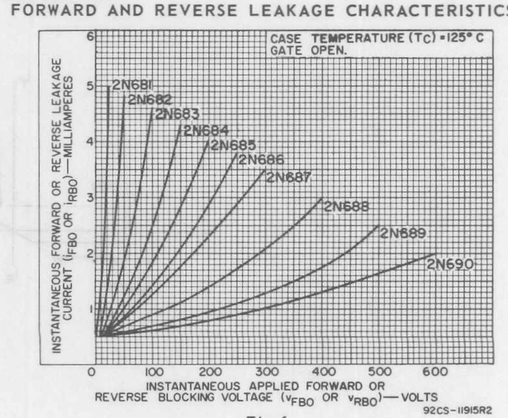
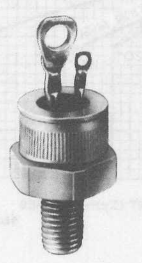


Fig. 6

RCA
Solid State
Division

Thyristors

S6431M



JEDEC TO-48 H-1601

Silicon Controlled Rectifier for High-Current Pulse Applications

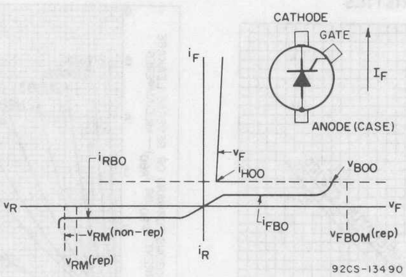
Features:

- **Up to 900 Amperes Peak Forward Current Pulses**
- **30 Watts Maximum Average Dissipation**
- **Forward Current of 35 Amperes (rms value)**
- **Shorted-Emitter Design**
- **All-Diffused Construction – Assures Exceptional Uniformity and Stability**
- **Direct Soldered Internal Construction – Assures Exceptional Resistance to Fatigue**

The S6431M (formerly RCA type 40216) is an all-diffused, three-junction silicon controlled rectifier (SCR) designed especially for use in radar pulse modulators, inverters, switching regulators, and other applications requiring a large ratio of peak to average current.

It is especially constructed for rapid spread of forward current over the full junction area to achieve a high rate of change of forward current (di/dt) capability and low switching dissipation.

TYPICAL E-I CHARACTERISTIC OF SILICON CONTROLLED-RECTIFIER



Absolute-Maximum Ratings

RATINGS	CONTROLLED-RECTIFIER TYPE	UNITS
	S6431M	
Transient Peak Reverse Voltage (Non-Repetitive), v_{RM} (non-rep)[a]	720	volts
Peak Reverse Voltage (Repetitive), v_{RM} (rep)[b]	600	volts
Peak Forward Blocking Voltage (Repetitive), v_{FBOM} (rep)[c]	600	volts
Forward Current:		
For case temperature of +65°C, RMS value, I_{FRMS}[d]	35	amperes
Peak Pulse Current (See *Fig.7*)	900	amperes
Rate of Change of Forward Current, di/dt[e]	See *Fig.7*	
Dynamic Dissipation:		
For case temperature of +65° C	30	watts
For other case temperatures	See *Fig.4*	
Gate Power*:		
Peak, Forward or Reverse, for 10 μs duration, P_{GM}[f] (See *Figs.10 and 11*)	40	watts
Average, P_{GAV}[g]	0.5	watt
Temperature:		
Storage, T_{stg}	–65 to +150	°C
Operating (Case), T_C	–65 to +125	°C

*Any values of peak gate current or peak gate voltage to give the maximum gate power is permissible.

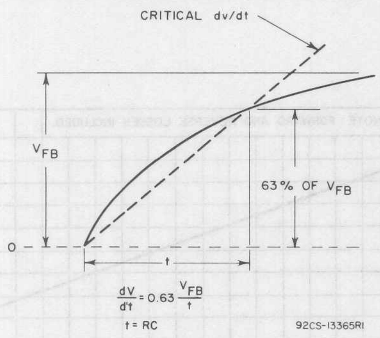


Fig. 1—Waveshape of critical dv/dt rating test.

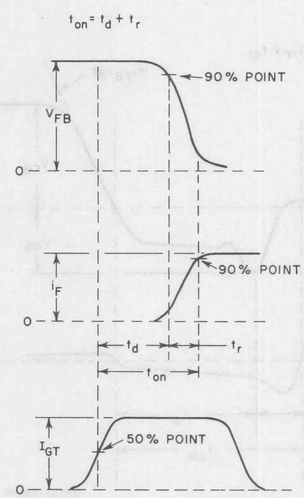


Fig. 2—Waveshape of t_{on} rating test.

Characteristics at Maximum Ratings (unless otherwise specified), and at Indicated Case Temperature (T_C)

CHARACTERISTICS	CONTROLLED-RECTIFIER TYPE			UNITS
	S6431M			
	Min.	*Typ.*	*Max.*	
Forward Breakover Voltage, v_{BOO}[h] At T_C = +125° C	600	–	–	volts
Instantaneous Blocking Current, At T_C = +125° C				
Forward, i_{FBO}[j]	–	–	10	mA
Reverse, i_{RBO}[k]	–	–	10	mA
Forward Voltage Drop, v_F[m]		See *Fig.5*		
DC Gate-Trigger Current, I_{GT}[n]: At T_C = +25° C (See *Fig.10*)	1	25	80	mA(dc)
DC Gate-Trigger Voltage, V_{GT}[p]: At T_C = +25° C (See *Fig.10*)	–	1.1	2	volts(dc)
Holding Current, i_{HOO}[q]: At T_C = +25° C	0.5	20	70	mA
Critical Rate of Applied Forward Voltage, Critical dv/dt[r] — $V_{FB} = v_{BOO}$ (min. value), exponential rise, and T_C = +125° C (See waveshape of *Fig.1*)	20	50	–	volts/ microsecond
Turn-On Time, t_{on}[s], (Delay Time + Rise Time) — $V_{FB} = v_{BOO}$ (min. value), i_F = 30 A, I_{GT} = 200 mA, 0.1 µs min. rise time, and T_C = +25° C (See waveshapes of *Fig.2*)	–	1.25	–	microsecond
Turn-Off Time, t_{off}[t], (Reverse Recovery Time + Gate Recovery Time) — i_F = 18 A, 50 µs pulse width, dv_{FB}/dt = 20 V/µs, di_r/dt = 30 A/µs, I_{GT} = 200 mA, and T_C = +80° C (See waveshapes of *Fig.3*)	15	20	40	microseconds
Thermal Resistance, Junction-to-Case	–	–	2	°C/W

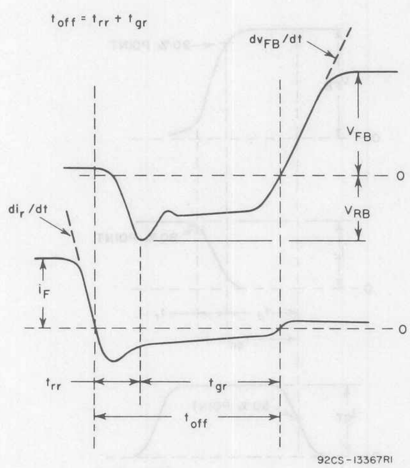


Fig. 3—Waveshape of t_{off} rating test.

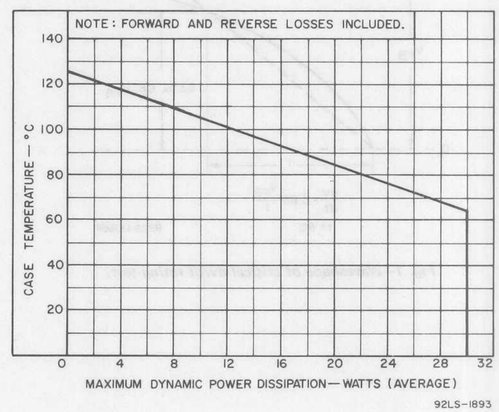


Fig. 4—Maximum average total power dissipation as a function of case temperature.

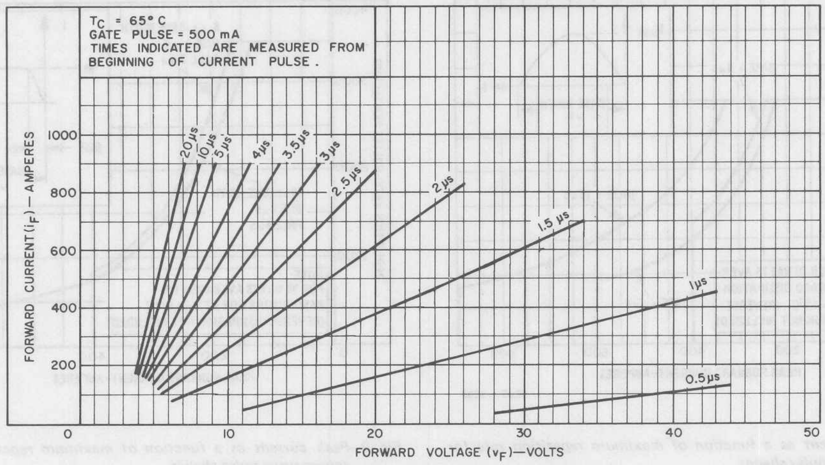


Fig. 5—Forward voltage-current characteristics as a function of time.

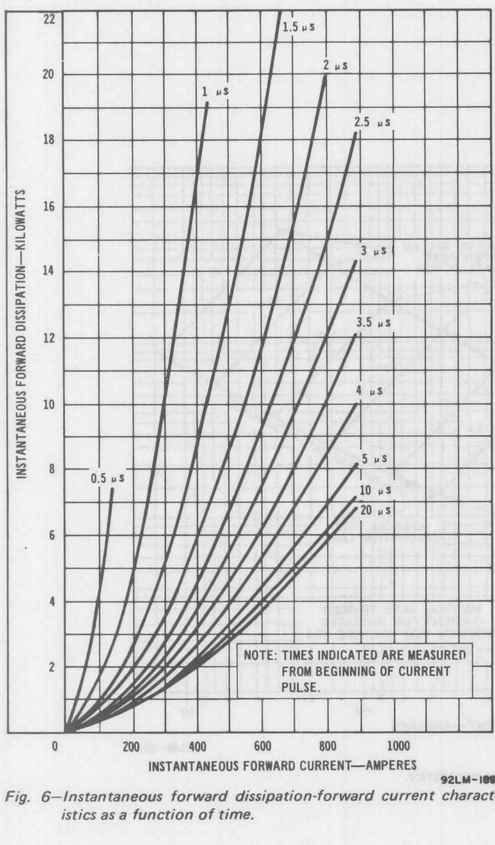


Fig. 6—Instantaneous forward dissipation-forward current characteristics as a function of time.

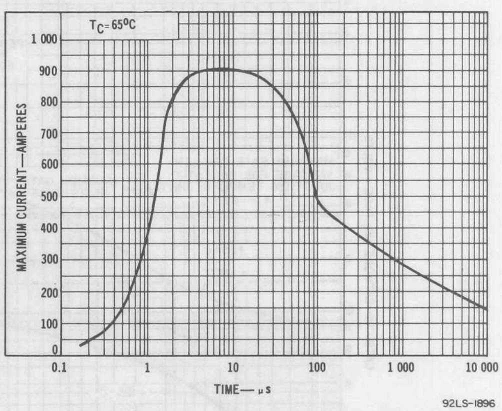


Fig. 7—Maximum current as a function of time.

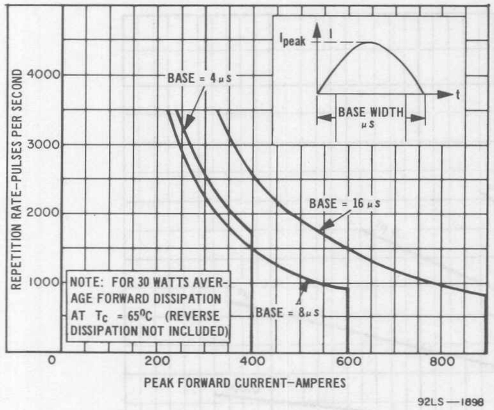


Fig. 8—Peak current as a function of maximum repetition rate for sine-wave pulse shapes.

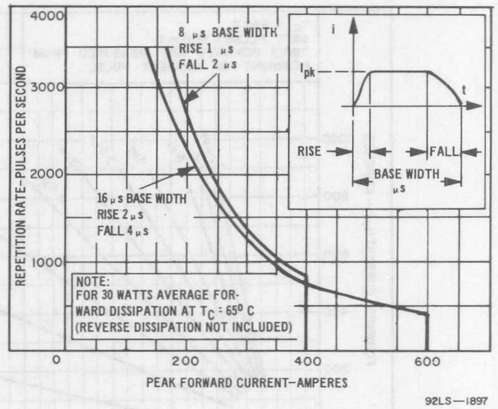


Fig. 9—Peak current as a function of maximum repetition rate for square-wave pulse shapes.

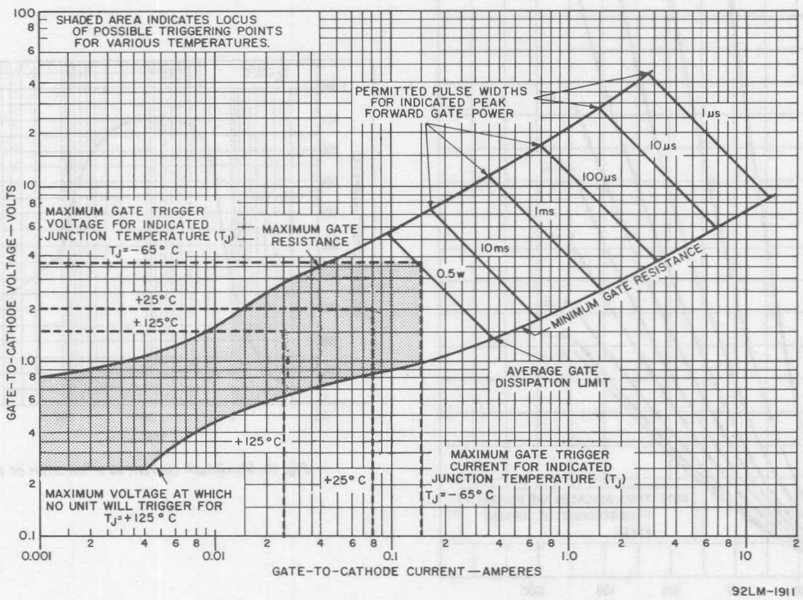


Fig. 10—Forward gate characteristics.

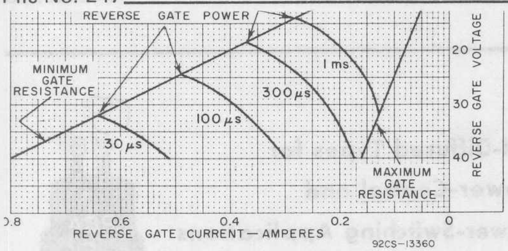


Fig. 11—Reverse gate characteristics.

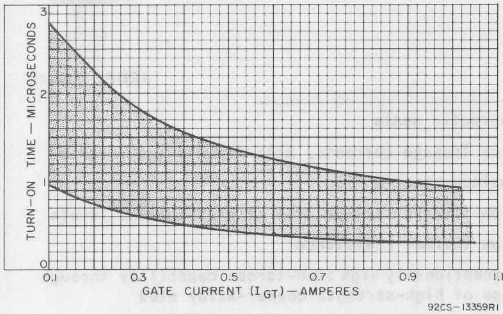
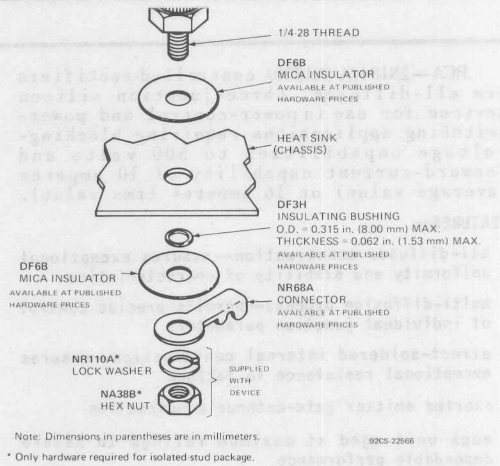


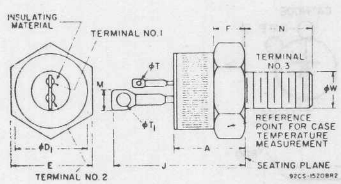
Fig. 12—Turn-on time characteristics.



In the United Kingdom, Europe, Middle East, and Africa, mounting-hardware policies may differ; check the availability of all items shown with your RCA sales representative or supplier.

Fig. 13 — Suggested mounting arrangement.

DIMENSIONAL OUTLINE
JEDEC TO-48



SYMBOL	INCHES		MILLIMETERS		NOTES
	MIN.	MAX.	MIN.	MAX.	
A	0.330	0.505	8.4	12.8	–
ϕD_1	–	0.544	–	13.81	–
E	0.544	0.562	13.82	14.28	–
F	0.113	0.200	2.87	5.08	3
J	0.950	1.100	24.13	27.94	–
M	0.215	0.225	5.46	5.71	1
N	0.422	0.453	10.72	11.50	–
ϕT	0.058	0.068	1.47	1.73	–
ϕT_1	0.138	0.148	3.51	3.75	–
ϕW	¼-28	UNF-2A	¼-28	UNF-2A	2

NOTES:
1. Contour and angular orientation of these terminals is optional.
2. Pitch diameter of ¼-28 UNF-2A (coated) threads (ASA B1. 1-1960).
3. A chamfer or undercut on one or both ends of hexagonal portion is optional.

TERMINAL CONNECTIONS

No.1 – Gate
No.2 – Cathode
Stud, No.3 – Anode

RCA

Solid State
Division

Thyristors

2N1842A 2N1845A 2N1848A
2N1843A 2N1846A 2N1849A
2N1844A 2N1847A 2N1850A

RCA—2N1842A-2N1850A controlled-rectifiers are all-diffused, three-junction silicon devices for use in power-control and power-switching applications requiring blocking-voltage capabilities to 500 volts and forward-current capability of 10 amperes (average value) or 16 amperes (rms value).

All-Diffused Types for Power-Control and Power-Switching Applications

JEDEC TO-48

FEATURES—

- all-diffused construction—assures exceptional uniformity and stability of characteristics
- multi-diffusion process—permits precise control of individual junction parameters
- direct-soldered internal construction—assures exceptional resistance to fatigue
- shorted emitter gate-cathode construction
- each unit aged at maximum ratings to assure dependable performance
- symmetrical gate-cathode construction—provides uniform current density, rapid electrical conduction, and efficient heat dissipation
- designed to meet stringent military environmental and mechanical specifications
- exceptionally rugged terminals
- hermetic seals
- low leakage currents, both forward and reverse
- welded construction
- low forward voltage drop at high current levels
- low thermal resistance
- exceptionally high stud-torque capability through use of high-strength copper-alloy stud

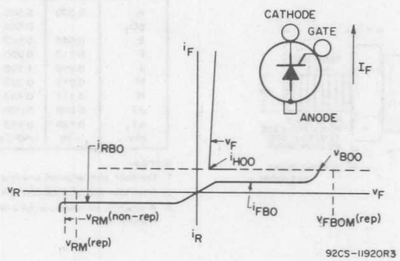


Fig.1 - Typical E-I Characteristic of Silicon Controlled-Rectifier.

Absolute-Maximum Ratings, for Operation with Sinusoidal AC Supply Voltage at a Frequency between 50 and 400 cps, and with Resistive or Inductive Load

RATINGS	SYMBOLS	* REF.	2N1842A	2N1843A	2N1844A	2N1845A	2N1846A	2N1847A	2N1848A	2N1849A	2N1850A	UNITS
TRANSIENT PEAK REVERSE VOLTAGE (NON-REPETITIVE)	v_{RM} (non-rep)	1	35	75	150	225	300	350	400	500	600	volts
PEAK REVERSE VOLTAGE (REPETITIVE)	v_{RM} (rep)	2	25	50	100	150	200	250	300	400	500	volts
PEAK FORWARD BLOCKING VOLTAGE (REPETITIVE)	v_{FBOM} (rep)	3	← 600 →									volts
AVERAGE FORWARD CURRENT:#	I_{FAV}	4										
For a case temperature# of +80° C and a conduction angle of 180°			← 10 →									amp
For other case temperatures and conduction angles			← See *Fig. 2* →									
PEAK SURGE CURRENT:	i_{FM}(surge)	5										
For one cycle of applied voltage			← 125 →									amp
For more than one cycle of applied voltage			← See *Fig. 3* →									
PEAK GATE POWER	P_{GM}	6	← 5 →									watts
AVERAGE GATE POWER	P_{GAV}	7	← 0.5 →									watt
PEAK FORWARD GATE CURRENT	i_{GKM}	8	← 2 →									amp
PEAK FORWARD GATE VOLTAGE:	v_{KGM}	9										
Forward			← 10 →									volts
Reverse			← 5 →									volts
TEMPERATURE:												
Storage	T_{stg}	-	← -65 to +125 →									°C
Operating (Case)#	T_C	-	← -65 to +125 →									°C
Operating (Free-air)	T_{FA}	-	← See *Fig. 4* →									

#Measured at the center of any of the six major faces on the perimeter of the hexagonal flange.

Electrical and Thermal Characteristics at Maximum Electrical Ratings (unless otherwise specified), and at Indicated Case Temperature, T_C

CHARACTERISTICS	SYMBOLS	* REF.	T_C °C	2N1842A	2N1843A	2N1844A	2N1845A	2N1846A	2N1847A	2N1848A	2N1849A	2N1850A	UNITS
Minimum Forward Breakover Voltage	v_{BOO}	10	+125	25	50	100	150	200	250	300	400	500	volts
Maximum Average Forward Blocking Current	I_{FBOAV}	11	+125	22.5	19	12.5	6.5	6	5.5	5	4	3	ma
Maximum Average Reverse Blocking Current	I_{RBOAV}	12	+125	22.5	19	12.5	6.5	6	5.5	5	4	3	ma
Maximum Average Forward Voltage Drop	V_{FAV}	13	+80	← 1.2 →									volts
Maximum DC Gate Trigger Current	I_{GT}	14	+125	← 45 →									ma
DC Gate-Trigger Voltage:	V_{GT}	15											
Maximum			-40	← 3.5 →									volts
			-65	← 3.7 →									volts
Minimum			+125	← 0.25 →									volt
			+100	← 0.3 →									volt
Holding Current (Typical)	i_{HOO}	16	+125	← 8 →									ma
Maximum Thermal Resistance, Junction-to-Case	θ_{JC}	17	-	← 2 →									°C/watt

* Numerical References are to Table of Terms, Symbols, and Definitions on page 4.

Measured at the center of any of the six major faces on the perimeter of the hexagonal flange.

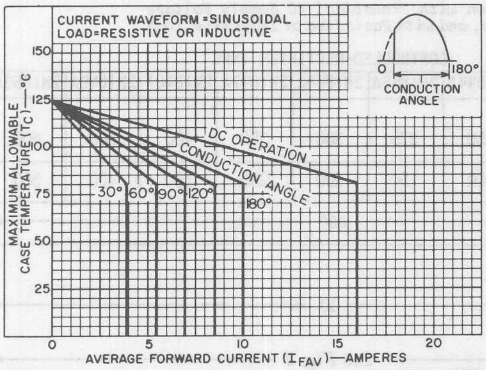


Fig. 2 - Rating Chart for Types 2N1842A through 2N1850A.

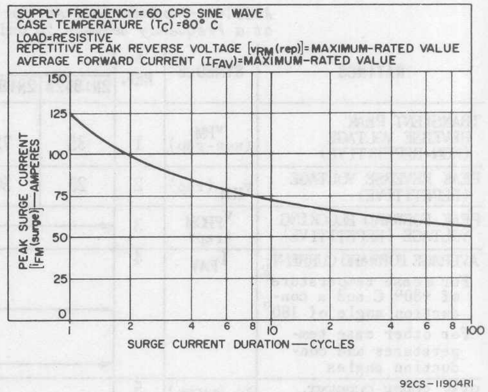


Fig. 3 - Surge Current Rating Chart for Types 2N1842A through 2N1850A.

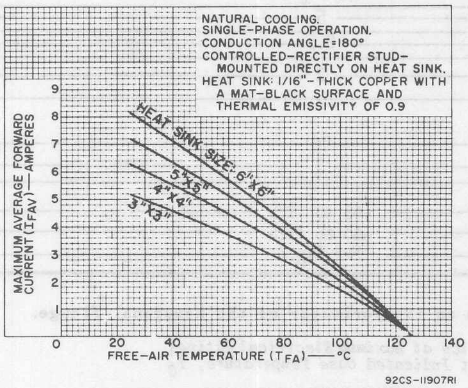


Fig. 4 - Operation Guidance Chart for Types 2N1842A through 2N1850A.

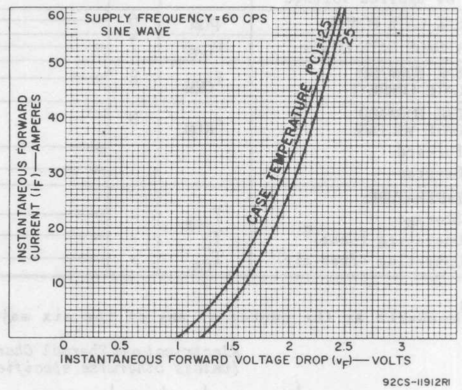


Fig. 5 - Maximum Forward Characteristics for Types 2N1842A through 2N1850A.

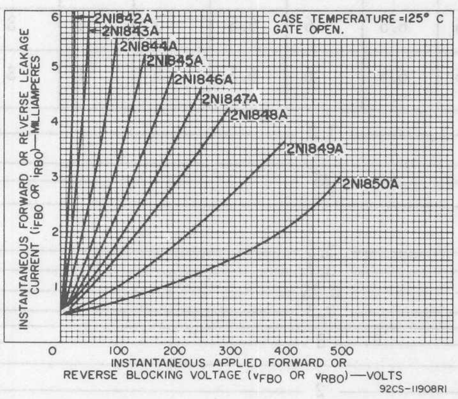


Fig. 6 - Typical Forward and Reverse Leakage Characteristics for Types 2N1842A through 2N1850A.

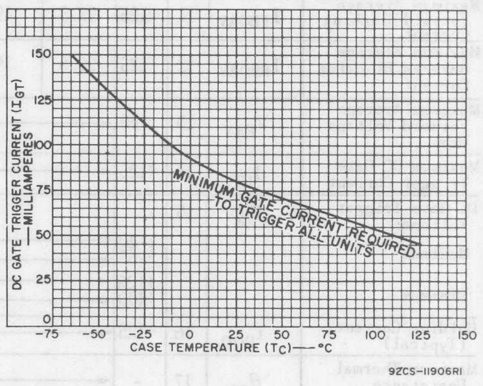


Fig. 7 - Gate Trigger-Current Characteristic for Types 2N1842A through 2N1850A.

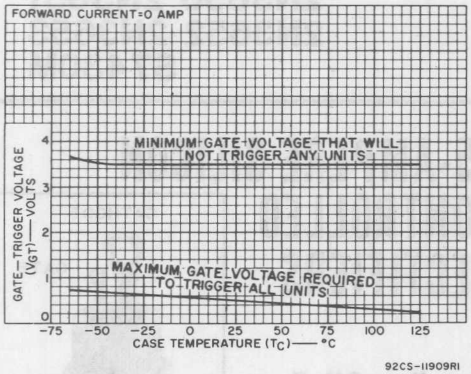
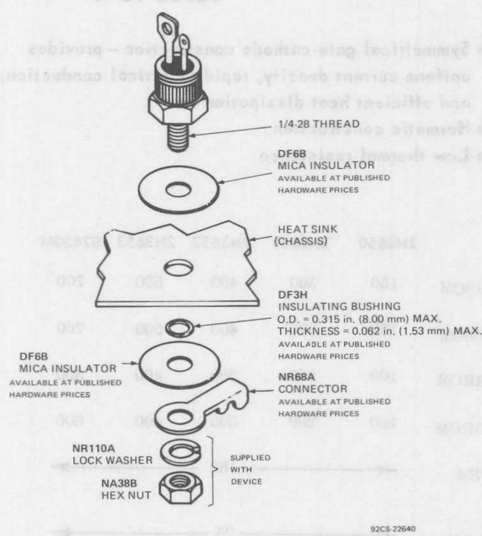


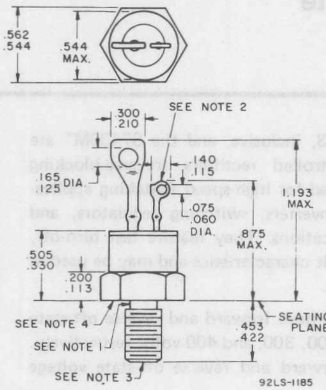
Fig. 8 - Gate Trigger-Voltage Characteristics for Types 2N1842A through 2N1850A.



In the United Kingdom, Europe, Middle East, and Africa, mounting-hardware policies may differ; check the availability of all items shown with your RCA sales representative or supplier.

Suggested Mounting Arrangement for Insulating Types 2N1842A-2N1850A from Heat Sink.

DIMENSIONAL OUTLINE
JEDEC TO-48



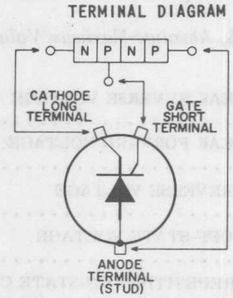
NOTE 1: COMPLETE THREADS TO EXTEND TO WITHIN 2 1/2 THREADS OF HEAD. DIA. OF UNTHREADED PORTION 0.249" MAXIMUM, 0.220" MINIMUM.

NOTE 2: ANGULAR ORIENTATION OF THESE TERMINALS IS UNDEFINED. SQUARE OR RADIUS ON END OF TERMINAL IS OPTIONAL.

NOTE 3: 1/4-28 UNF-2A. MAXIMUM PITCH DIA. OF PLATED THREADS SHALL BE BASIC PITCH DIA. 0.2268", MINIMUM PITCH DIA. 0.2225". REF. (SCREW THREAD STANDARDS FOR FEDERAL SERVICES 1957) HANDBOOK H28 1957 P1.

NOTE 4: A CHAMFER (OR UNDERCUT) ON ONE OR BOTH ENDS OF HEXAGONAL PORTION IS OPTIONAL.

TERMINAL DIAGRAM

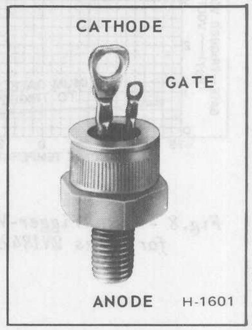


RCA
Solid State
Division

Thyristors
2N3650 2N3651 2N3652 2N3653 S7430M

35-AMPERE SILICON CONTROLLED RECTIFIERS

Fast Turn-Off Types for Inverter and Pulse Applications



JEDEC TO-48

RCA-2N3650 to 2N3653, inclusive, and the S7430M* are all-diffused silicon controlled rectifiers (reverse-blocking triode thyristors) intended for high-speed switching applications such as power inverters, switching regulators, and high-current pulse applications. They feature fast turn-off, high dv/dt, and high di/dt characteristics and may be used at frequencies up to 25 kHz.

The 2N3650 to 2N3653 have forward and reverse off-state voltage ratings of 100, 200, 300, and 400 volts, respectively. Type S7430M has a forward and reverse off-state voltage rating of 600 volts.

Formerly RCA Type No. 40735

FEATURES

- **Fast turn-off time – 15 μs max.**
- **High di/dt and dv/dt capabilities**
- **High peak-current capability**
- **Shorted-emitter gate-cathode construction**
- **Forward and reverse gate dissipation ratings**
- **All-diffused construction – assures exceptional uniformity and stability of characteristics**
- **Symmetrical gate-cathode construction – provides uniform current density, rapid electrical conduction, and efficient heat dissipation**
- **Hermetic construction**
- **Low thermal resistance**

MAXIMUM RATINGS, *Absolute-Maximum Values:*

		2N3650	2N3651	2N3652	2N3653	S7430M	
*NON-REPETITIVE PEAK REVERSE VOLTAGE Gate Open	V_{RSOM}	150	300	400	500	700	V
NON-REPETITIVE PEAK FORWARD VOLTAGE Gate Open	V_{DSOM}	150	300	400	500	700	V
*REPETITIVE PEAK REVERSE VOLTAGE Gate Open	V_{RROM}	100	200	300	400	600	V
*REPETITIVE PEAK OFF-STATE VOLTAGE Gate Open	V_{DROM}	100	200	300	400	600	V
*PEAK SURGE (NON-REPETITIVE) ON-STATE CURRENT: For one cycle of applied principal voltage (60 Hz, sinusoidal)	I_{TSM}	← 180 →					A
ON-STATE CURRENT: For case temperature (T_C) = 25 °C							
* Average DC value, conduction angle of 180°	$I_{T(AV)}$	← 25 →					A
RMS value	$I_{T(RMS)}$	← 35 →					A
*RATE-OF-CHANGE OF ON-STATE CURRENT: $V_{DM} = V_{(BO)O}$, I_{GT} = 200 mA, t_r = 0.1 μs (See Fig. 2)	di/dt	← 400 →					A/μs
*GATE POWER DISSIPATION							
PEAK FORWARD (for 10 μs max.)	P_{GM}	← 40 →					W
AVERAGE (averaging time = 10 ms, max.)	$P_{G(AV)}$	← 1 →					W
*TEMPERATURE RANGE							
Storage		← -65 to 150 →					°C
Operating (Case)		← -65 to 120 →					°C
Soldering (10 s max. for case)		← 225 →					°C

*In accordance with JEDEC registration data format (JS-14, RDF1)-- applies to the JEDEC (2N-Series) types only.

35-A SCR's

ELECTRICAL CHARACTERISTICS, ***At Maximum Ratings and at Indicated Case Temperature (T_C) Unless Otherwise Specified***

CHARACTERISTIC	SYMBOL	LIMITS															UNITS
		Type 2N3650			Type 2N3651			Type 2N3652			Type 2N3653			Type S7430M			
		MIN.	TYP.	MAX.	MIN.	TYP.	MAX.	MIN.	TYP.	MAX.	MIN.	TYP.	MAX.	MIN.	TYP.	MAX.	
INSTANTANEOUS FORWARD BREAKOVER VOLTAGE: Gate Open, T_C = 120 °C	$v_{(BO)O}$	100	–	–	200	–	–	300	–	–	400	–	–	600	–	–	V
* PEAK OFF-STATE CURRENT: (Gate Open, T_C = 120 °C) FORWARD, V_{DO} = V_{DROM}	I_{DOM}	–	–	6	–	–	6	–	–	5.5	–	–	4	–	–	3	mA
REVERSE, V_{RO} = V_{RROM}	I_{RROM}	–	–	6	–	–	6	–	–	5.5	–	–	4	–	–	3	mA
* INSTANTANEOUS ON-STATE VOLTAGE: For i_T = 25 A, T_C = 25 °C	v_T	–	–	2.05	–	–	2.05	–	–	2.05	–	–	2.05	–	–	2.05	V
DC GATE TRIGGER CURRENT: V_D = 6 V (DC), R_L = 4 Ω, T_C = 25 °C	I_{GT}	–	80	180	–	80	180	–	80	180	–	80	180	–	80	180	mA
V_D = 6 V (DC), R_L = 2 Ω, T_C = -65 °C	I_{GT}	–	150	500*	–	150	500*	–	150	500*	–	150	500*	–	150	500	mA
DC GATE TRIGGER VOLTAGE: V_D = 6 V (DC), R_L = 4 Ω, T_C = 25 °C	V_{GT}	–	1.5	3	–	1.5	3	–	1.5	3	–	1.5	3	–	1.5	3	V
V_D = V_{DROM}, R_L = 200 Ω, T_C = 120 °C	V_{GT}	0.25*	–	–	0.25*	–	–	0.25*	–	–	0.25*	–	–	0.25	–	–	V
V_D = 6 V (DC), R_L = 2 Ω, T_C = -65 °C	V_{GT}	–	2	4.5*	–	2	4.5*	–	2	4.5*	–	2	4.5*	–	2	4.5	V
INSTANTANEOUS HOLDING CURRENT: Gate Open At T_C = 25 °C	i_{HO}	–	75	150	–	75	150	–	75	150	–	75	150	–	75	150	mA
* At T_C = -65 °C	i_{HO}	–	150	350	–	150	350	–	150	350	–	150	350	–	150	350	mA
* CRITICAL RATE-OF-RISE OF OFF-STATE VOLTAGE: V_{DO} = V_{DROM} Exponential rise, T_C = 120 °C, (See Fig. 4.)	dv/dt	200	–	–	200	–	–	200	–	–	200	–	–	200	–	–	V/μs
CIRCUIT COMMUTATED TURN-OFF TIME (Rectangular Pulse): V_{DX} = V_{DROM}, i_T = 10 A (pulse duration = 50 μs), I_{GT} = 200 mA at turn-on, -di/dt = 5 A/μs, dv/dt = 200 V/μs, V_{RX} = 15 min., V_{GK} = 0 V (at turn-off), T_C = 120 °C (See Fig. 4 & 5)	t_q	–	11	15	–	11	15	–	11	15	–	11	15	–	11	15	μs
CIRCUIT COMMUTATED TURN-OFF TIME (Half-Sinusoidal Waveform): V_{DX} = V_{DROM}, i_T = 100 A (pulse duration = 1.5 μs), I_{GT} = 200 mA dv/dt = 200 V/μs, V_{RX} = 30 V min., V_{GK} = 0 V (at turn-off), T_C = 115 °C (See Fig. 6 & 7)	t_q	–	12	15*	–	12	15*	–	12	15*	–	12	15*	–	12	15	μs
* THERMAL RESISTANCE: Junction-to-Case	θ_{J-C}	–	–	1.7	–	–	1.7	–	–	1.7	–	–	1.7	–	–	1.7	°C/W

*In accordance with JEDEC registration data format (JS-14, RD 1) -- applies to the JEDEC (2N-Series) types only.

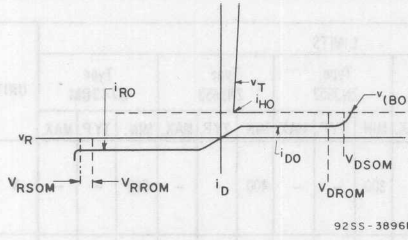


Fig. 1—Principal voltage-current characteristic.

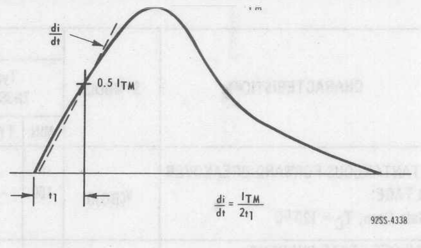


Fig. 2—Rate of change of on-state current with time (defining di/dt).

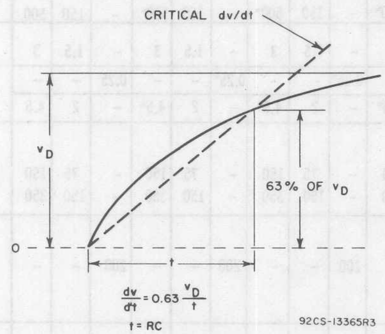


Fig. 3—Rate of rise of off-state voltage with time (defining dv/dt).

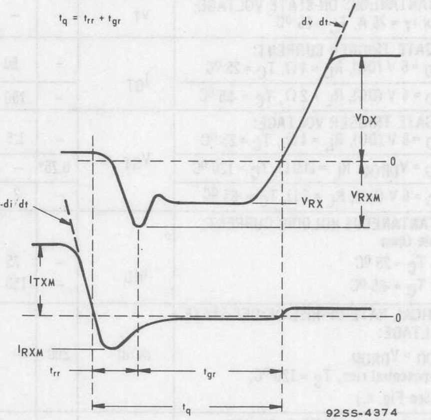


Fig. 4—Relationship between off-state voltage, reverse voltage, on-state current, and reverse current, showing reference points defining turn-off time (t_q), rectangular pulse.

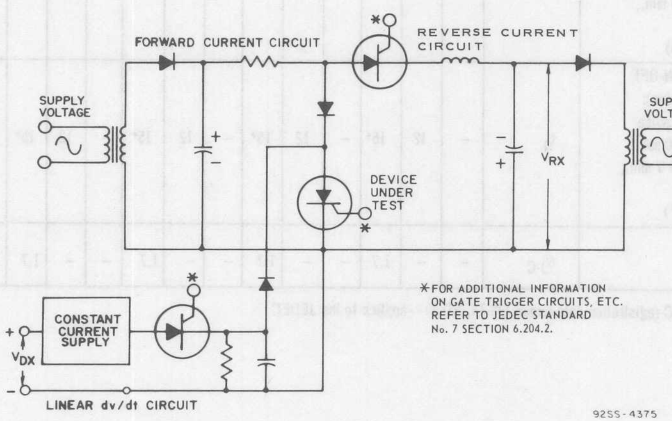


Fig. 5—Circuit used to measure turn-off time (t_q), rectangular pulse.

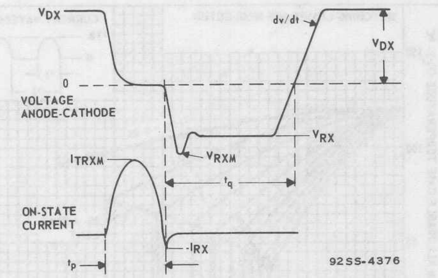


Fig. 6—Relationship between off-state voltage, reverse voltage, on-state current, and reverse current showing reference points for specification of turn-off time (t_q), half sine wave pulse.

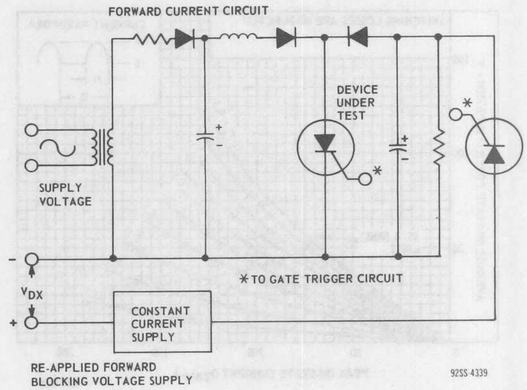


Fig. 7—Circuit used to measure turn-off time (t_q), half sine wave pulse.

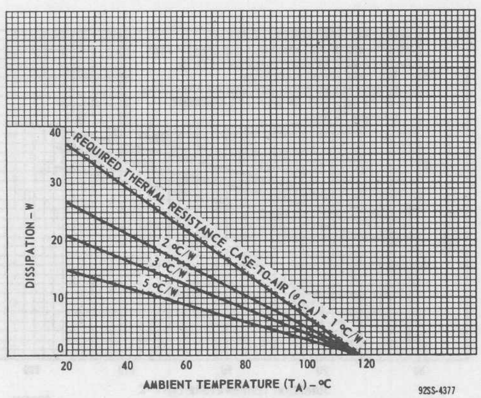


Fig. 8—Heat sink guidance.

COOLING CONSIDERATIONS

The overall thermal resistance, case to air, needed to operate these devices at a given current and a specific ambient air temperature is shown in Fig. 8. For example: dissipation of 20 watts and an ambient air temperature of 43 °C (110 °F), the required thermal resistance, case to air, is 2 °C/W. This required case-to-air thermal resistance included both case-to-heat sink and heat sink-to-air thermal resistances.

Typical values of case-to-heat sink thermal resistances for different mounting arrangements are shown in Table 1. Thermal resistance characteristics of commercial heat sinks are contained in various manufacturers' data sheets.

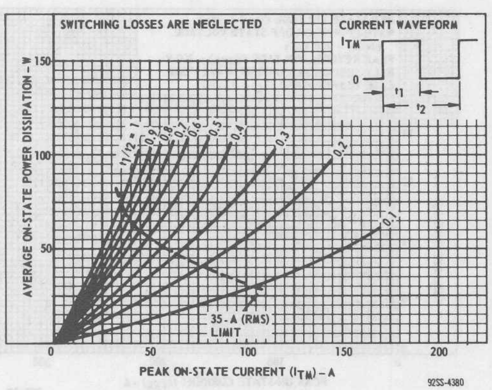


Fig. 9—Power dissipation vs. on-state current.

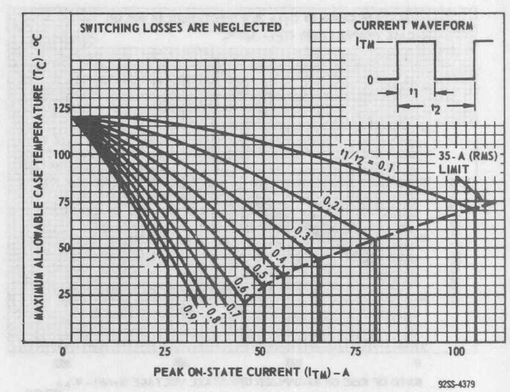


Fig.10—Maximum allowable case-temperature vs. on-state current.

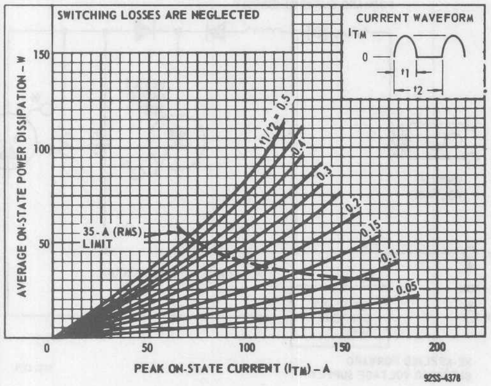


Fig. 11—Power dissipation vs. on-state current.

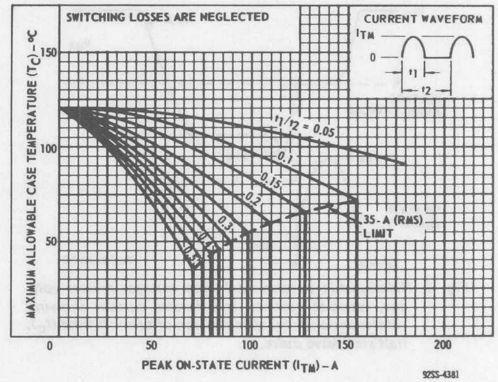


Fig. 12—Maximum allowable case-temperature vs. on-state current.

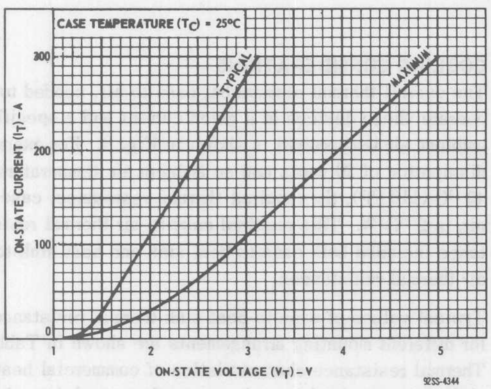


Fig. 13—Variation of on-state current with on-state voltage.

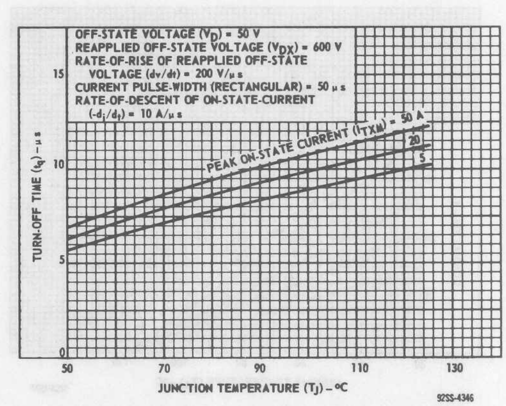


Fig. 14—Typical variation of turn-off time with junction temperature (rectangular pulse).

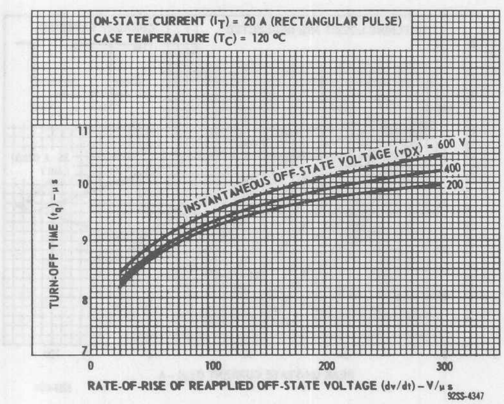


Fig. 15—Typical variation of turn-off time with rate of rise of reapplied off-state voltage (rectangular pulse).

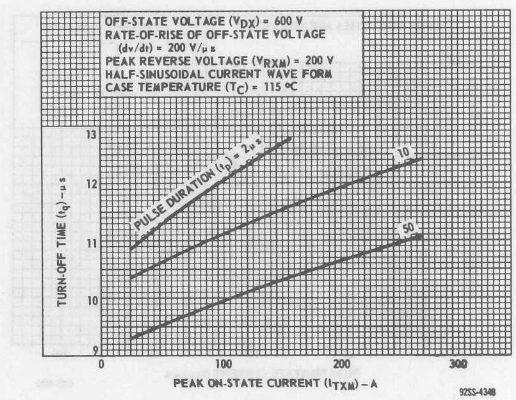


Fig. 16—Typical variation of turn-off time with peak on-state current (half-sinusoidal pulse).

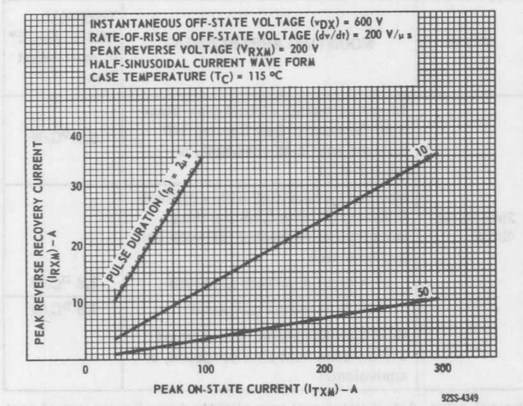


Fig. 17—Typical variation of peak reverse recovery current with peak on-state current (half) sinusoidal pulse).

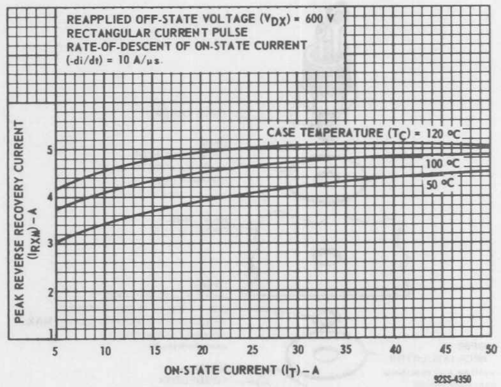


Fig. 18—Typical variation of peak reverse-recovery current with on-state current.

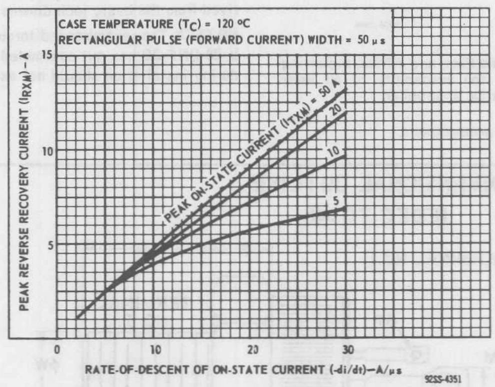


Fig. 19—Typical variation of peak reverse recovery current with rate of descent of on-state current.

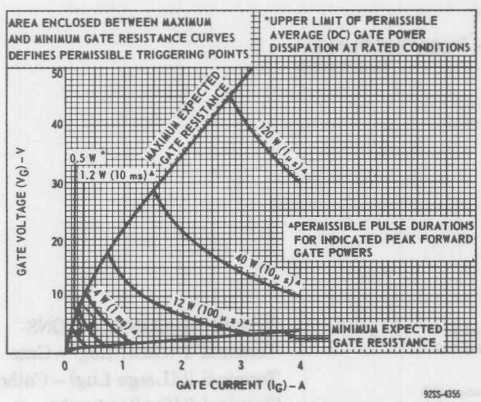


Fig. 20—Typical forward-biased gate characteristics.

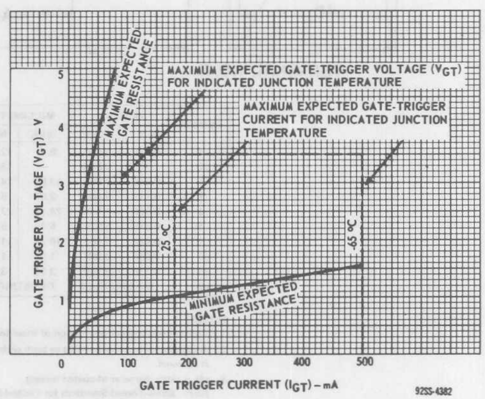
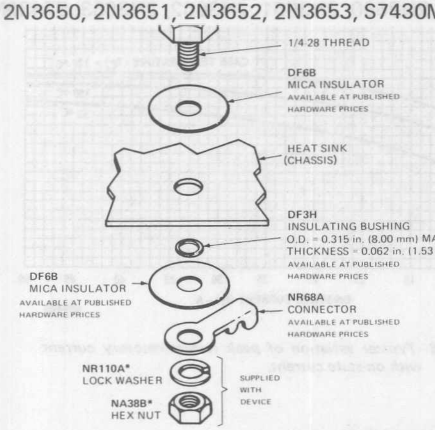


Fig. 21—Typical gate trigger characteristics.



Note: Dimensions in parentheses are in millimeters.

* Only hardware required for isolated-stud package.

In the United Kingdom, Europe, Middle East, and Africa, mounting-hardware policies may differ; check the availability of all items shown with your RCA sales representative or supplier.

Fig. 22–Suggested mounting arrangement.

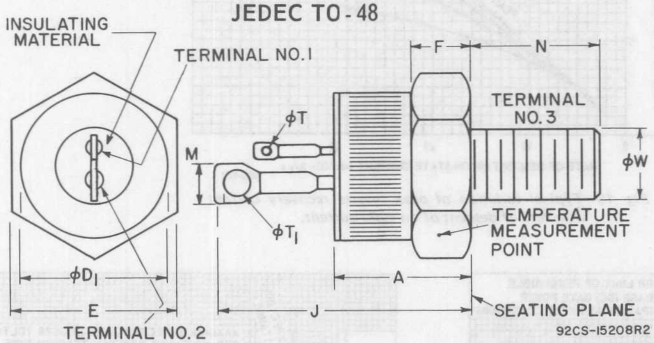
	Directly mounted on heat sink (Heat-Sink Compound: Dow Corning 340 silicone heat-sink compound, or equivalent.)	0.9 °C/W
2N3650-53 40735	Mounted on heat sink with a 0.004 to 0.006-in. (0.10 to 0.15-mm) thick mica insulating washer (between unit and heat sink).	
	Without heat-sink compound	2.8 °C/W
	With heat-sink compound Heat-Sink Compound: Dow Corning 340 silicone heat-sink compound, or equivalent.)	1.8 °C/W

*Normal value. Actual value will vary slightly depending on use of heat sink compound, mounting surface, insulator thickness, mounting torque, and etc.

NOTE 1: Dimensions in parentheses are in millimeters and are derived from the basic inch dimensions as indicated.

NOTE 2: The recommended torque is 26 to 36 in. – lb. applied to a ¼-28 UNF-2B hex nut assembled on thread. The applied torque during installation should not exceed 50 in. – lb.

DIMENSIONAL OUTLINE
JEDEC TO-48



SYMBOL	INCHES		MILLIMETERS		NOTES
	MIN.	MAX.	MIN.	MAX.	
A	0.330	0.505	8.4	12.8	–
ϕD_1	–	0.544	–	13.81	–
E	0.544	0.562	13.82	14.28	–
F	0.113	0.200	2.87	5.08	2
J	0.950	1.100	24.13	27.94	–
M	0.215	0.225	5.46	5.71	
N	0.422	0.453	10.72	11.50	–
ϕT	0.058	0.068	1.47	1.73	1
ϕT_1	0.138	0.148	3.51	3.75	1
ϕW	1/4-28 UNF-2A		1/4-28 UNF-2A		2

NOTES:
1. Contour and angular orientation of these terminals is optional.
2. A chamfer or undercut on one or both ends of hexagonal portion is optional.
3. ϕW is pitch diameter of coated threads.
REF: Screw-Thread Standards for Federal Services, Handbook H28, Part I. Recommended Torque: 25 inch-pounds.

TERMINAL CONNECTIONS
Terminal 1 (Small Lug) – Gate
Terminal 2 (Large Lug) – Cathode
Terminal 3 (Stud) – Anode

RCA

Solid State Division

Thyristors

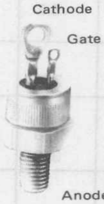
2N3654 2N3655 2N3656 2N3657 2N3658 S7432M

35-A Silicon Controlled Rectifiers

For Inverter Applications

Cathode

Gate



Anode

JEDEC TO-48 H-1601

Features:

- **Fast turn-off time — 10 μs max.**
- **High di/dt and dv/dt capabilities**
- **Shorted-emitter gate-cathode construction . . . contains an internally diffused resistor between gate and cathode**
- **Low thermal resistance**
- **Center gate construction . . . provides rapid uniform gate-current spreading for faster turn-on with substantially reduced heating effects**

These RCA types are all-diffused, silicon controlled rectifiers designed for high-frequency power-switching applications such as inverters, switching regulators, and high-current pulse applications. These types may be used at frequencies up to 25 kHz.

MAXIMUM RATINGS, *Absolute-Maximum Values:*

Rating	Symbol	2N3654	2N3655	2N3656	2N3657	2N3658	S7432M	Units
***NON-REPETITIVE PEAK REVERSE VOLTAGE:●**								
Gate Open	V_{RSOM}	75	150	300	400	500	700	V
NON-REPETITIVE PEAK OFF-STATE VOLTAGE:●								
Gate Open	V_{DSOM}	75	150	300	400	500	700	V
***REPETITIVE PEAK REVERSE VOLTAGE:●**								
Gate Open	V_{RROM}	50	100	200	300	400	600	V
***REPETITIVE PEAK OFF-STATE VOLTAGE:●**								
Gate Open	V_{DROM}	50	100	200	300	400	600	V
ON-STATE CURRENT:								
$T_C = 40^\circ C$, conduction angle = 180°:								
RMS	$I_{T(RMS)}$	35						A
* Average	$I_{T(AV)}$	25						A
***PEAK SURGE (NON-REPETITIVE) ON-STATE CURRENT:**	I_{TSM}							
For one full cycle of applied principal voltage 60 Hz (sinusoidal)		180						A
***RATE OF CHANGE OF ON-STATE CURRENT:**								
$V_D = V_{DROM}$, $I_{GT} = 200$ mA, $t_r = 0.1$ μs (See Fig. 15)	di/dt	400						A/μs
FUSING CURRENT (for SCR protection):								
$T_J = -65$ to $120^\circ C$, t = 1 to 8.3 ms	I^2t	165						A^2s
***GATE POWER DISSIPATION:■**								
Peak Forward (for 10 μs max., See Fig. 7)	P_{GM}	40						W
Average (averaging time = 10 ms max.)	$P_{G(AV)}$	1						W
***TEMPERATURE RANGE:▲**								
Storage	T_{stg}	−65 to 150						°C
Operating (Case)	T_C	−65 to 120						°C
TERMINAL TEMPERATURE (During soldering):	T_T							
For 10 s max. (terminals and case)		225						°C
STUD TORQUE:	τ_S							
Recommended		35						in-lb
Maximum (DO NOT EXCEED)		50						in-lb

* In accordance with JEDEC registration data format (JS-14, RDF-1) filed for the JEDEC (2N series) types.

● These values do not apply if there is a positive gate signal. Gate must be open or negatively biased.

■ Any product of gate current and gate voltage which results in a gate power less than the maximum is permitted.

▲ For temperature measurement reference point, see Dimensional Outline.

ELECTRICAL CHARACTERISTICS

At Maximum Ratings Unless Otherwise Specified and at Indicated Case Temperature (T_C)

CHARACTERISTIC	SYMBOL	LIMITS FOR ALL TYPES Except as Specified			UNITS
		MIN.	TYP.	MAX.	
* Peak Off-State Current: (Gate open, T_C = 120°C) Forward Current (I_{DOM}) at $V_D = V_{DROM}$ Reverse Current (I_{ROM}) at $V_R = V_{RROM}$	I_{DOM} or I_{ROM}				mA
2N3654, 2N3655, 2N3656, S7432M		–	–	6	
2N3657		–	–	5.5	
2N3658		–	–	4	
* Instantaneous On-State Voltage: i_T = 25 A (peak), T_C = 25°C	v_T	–	–	2.05	V
Instantaneous Holding Current: Gate open, T_C = 25°C	I_{HO}	–	75	150	mA
T_C = −65°C		–	150	350*	
* Critical Rate of Rise of Off-State Voltage: $V_D = V_{DROM}$, exponential voltage rise, Gate open, T_C = 120°C (See Fig. 16)	dv/dt	200	–	–	V/µs
DC Gate Trigger Current: V_D = 6 V (dc), R_L = 4 Ω, T_C = 25°C	I_{GT}	–	80	180	mA
V_D = 6 V (dc), R_L = 2 Ω, T_C = −65°C		–	150	500*	
DC Gate Trigger Voltage: V_D = 6 V (dc), R_L = 4 Ω, T_C = 25°C	V_{GT}	–	1.5	3	V
$V_D = V_{DROM}$, R_L = 200 Ω, T_C = 120°C		0.25*	–	–	
V_D = 6 V (dc), R_L = 2 Ω, T_C = −65°C		–	2	4.5*	
* Circuit Commutated Turn-Off Time: (Rectangular Pulse) $V_{DX} = V_{DROM}$, i_T = 10 A, pulse duration = 50 µs, dv/dt = 200 V/µs, – di/dt = –5 A/µs, I_{GT} = 200 mA, V_{RX} = 15 V min., V_{GK} = 0 V (at turn-off), T_C = 120°C (See Figs. 19 & 20)	t_q	–	–	10	µs
* Circuit Commutated Turn-Off Time: (Sinusoidal Pulse) $V_{DX} = V_{DROM}$, i_T = 100 A, pulse duration = 1.5 µs, dv/dt = 200 V/µs, V_{RX} = 30 V min., V_{GK} = 0 V (at turn-off) T_C = 115°C (See Figs. 17 & 18)	t_q	–	..	10	µs
* Thermal Resistance Junction-to-Case: Steady-State	R_{θ}-JC	–	–	1.7	°C/W

* In accordance with JEDEC registration data format (JS-14, RDF-1) filed for the JEDEC (2N-series) types.

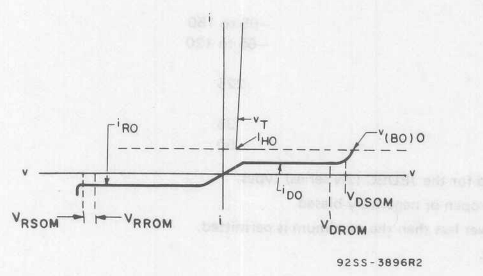


Fig. 1 – Principal voltage-current characteristic.

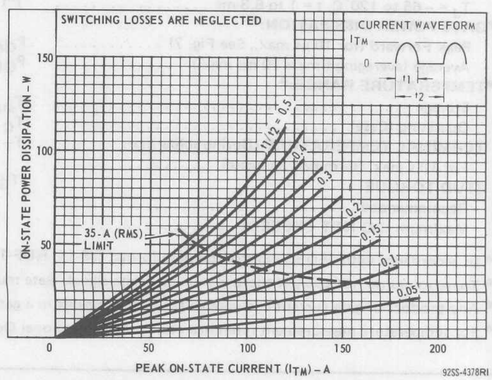


Fig. 2 – Power dissipation vs. peak on-state current.

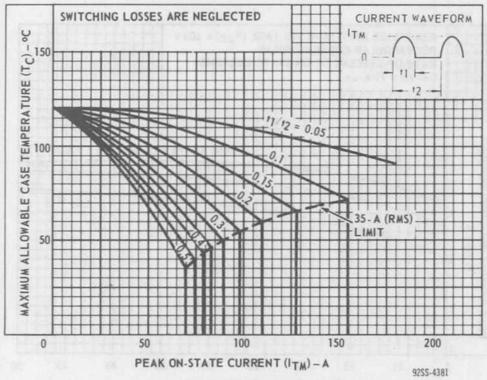


Fig. 3 — Maximum allowable case-temperature vs. peak on-state current.

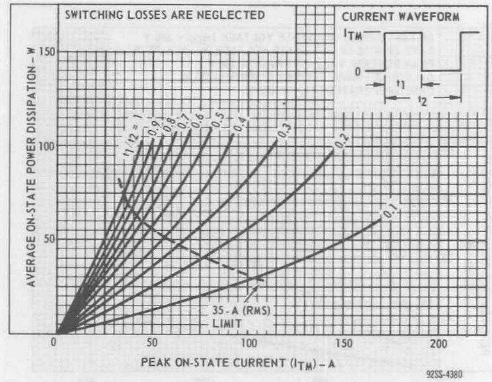


Fig. 4 — Power dissipation vs. peak on-state current.

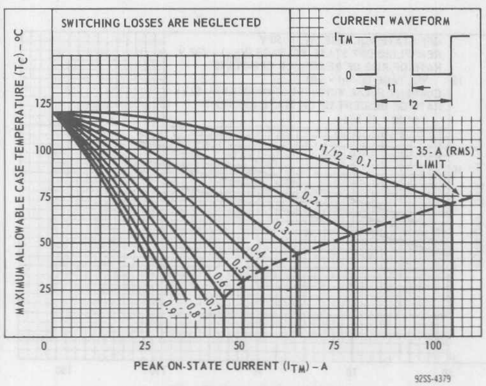


Fig. 5 — Maximum allowable case-temperature vs. peak on-state current.

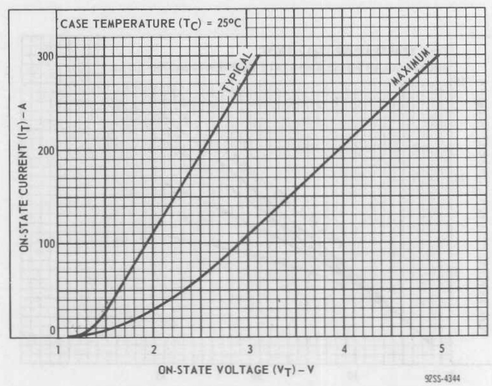


Fig. 6 — Variation of on-state current with on-state voltage.

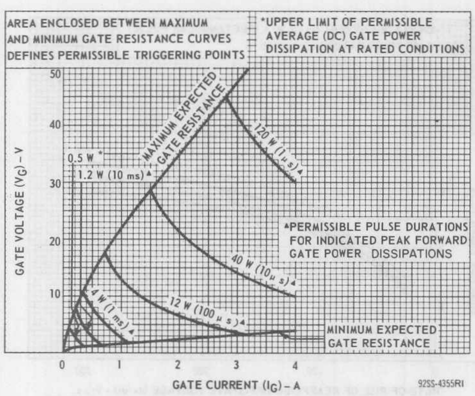


Fig. 7 — Typical forward-biased gate characteristics.

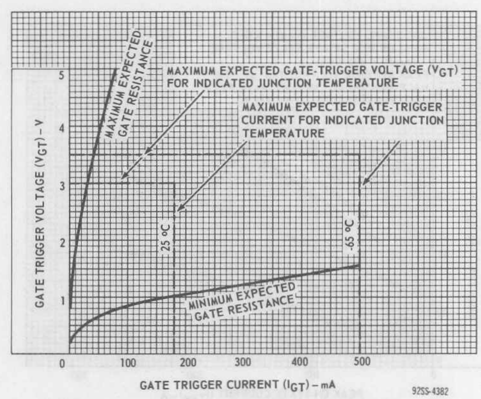


Fig. 8 — Typical gate-trigger characteristics.

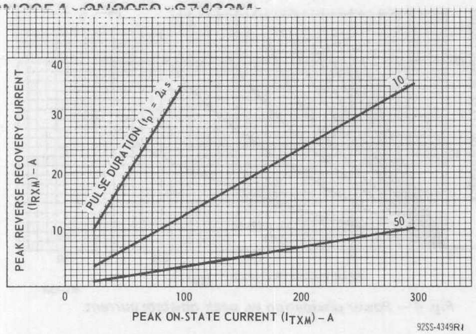


Fig. 9 — Typical variation of peak reverse-recovery current with peak on-state current (half-sine-wave pulse).

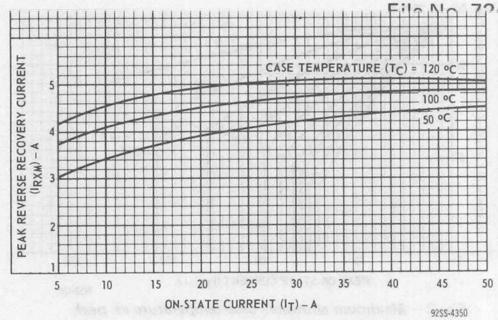


Fig. 10 — Typical variation of peak reverse-recovery current with on-state current (rectangular pulse).

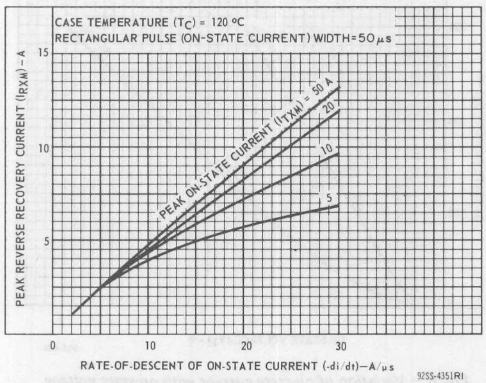


Fig. 11 — Typical variation of peak reverse-recovery current with rate-of-descent of on-state current (rectangular pulse).

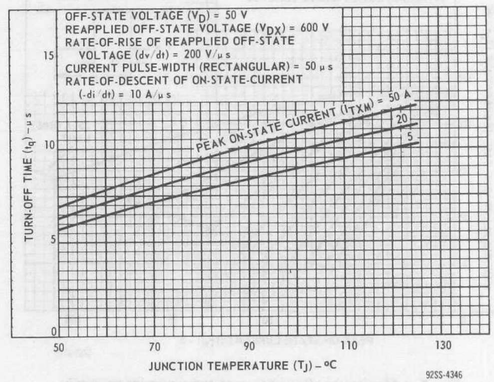


Fig. 12 — Typical variation of turn-off time with junction temperature (rectangular pulse).

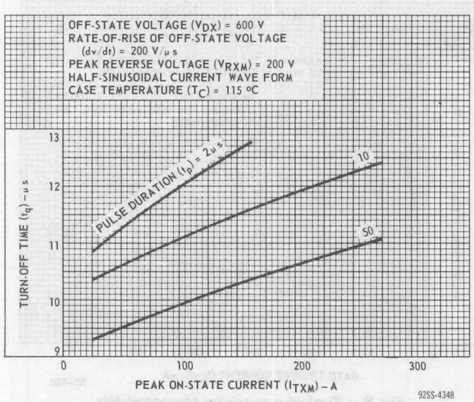


Fig. 13 — Typical variation of turn-off time with peak on-state current (half-sine-wave pulse).

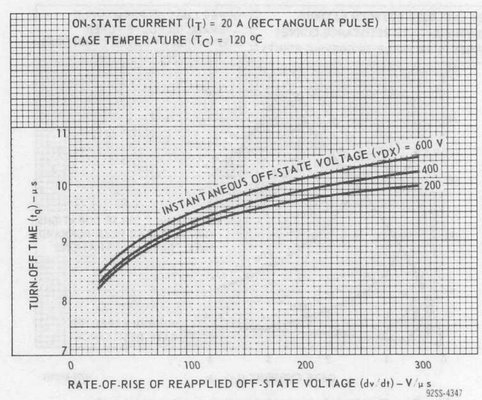


Fig. 14 — Typical variation of turn-off time with rate-of-rise of reapplied off-state voltage (rectangular pulse).

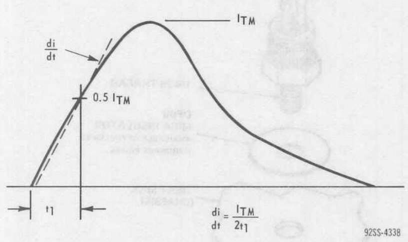


Fig. 15 – Rate-of-change of on-state current with time (defining di/dt).

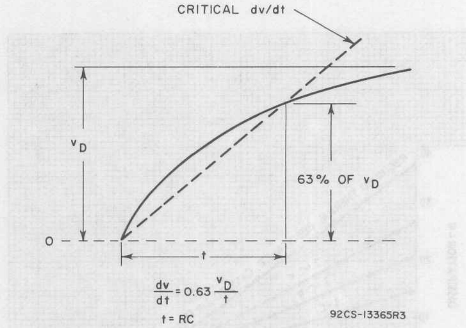


Fig. 16 – Rate-of-rise of off-state voltage with time (defining dv/dt).

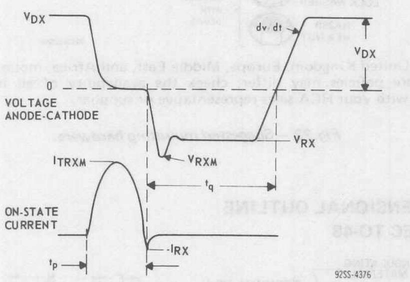


Fig. 17 – Relationship between off-state voltage, reverse voltage, on-state current, and reverse current showing reference points for specification of turn-off time (t_q), half-sine-wave pulse.

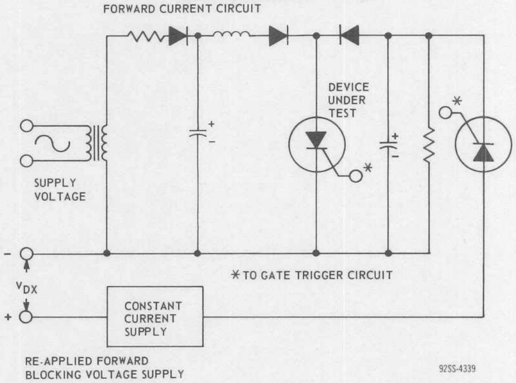


Fig. 18 – Circuit used to measure turn-off time (t_q), half-sine-wave pulse.

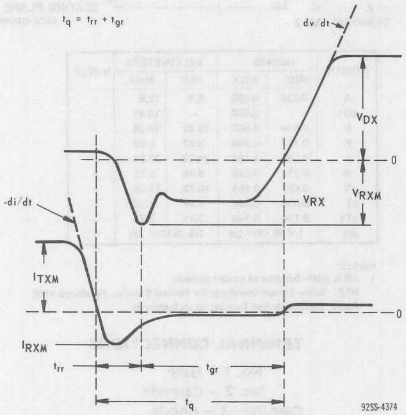


Fig. 19 – Relationship between off-state voltage, reverse voltage, on-state current, and reverse current showing reference points defining turn-off time (t_q), rectangular pulse.

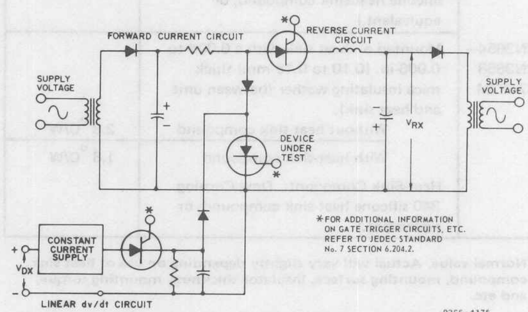


Fig. 20 – Circuit used to measure turn-off time (t_q), rectangular pulse.

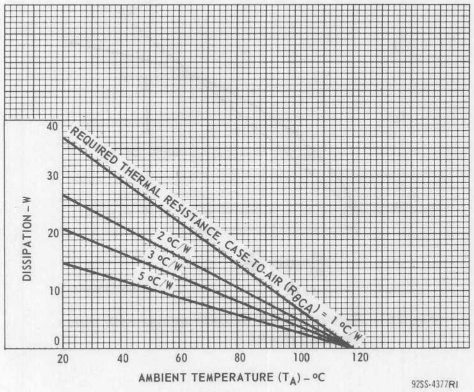
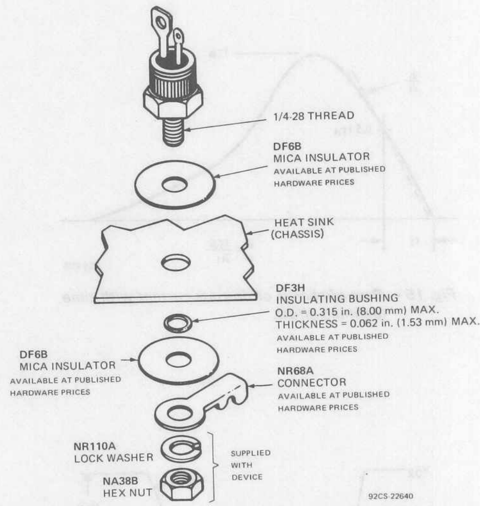


Fig. 21 – Heat sink guidance.



In the United Kingdom, Europe, Middle East, and Africa, mounting-hardware policies may differ; check the availability of all items shown with your RCA sales representative or supplier.

Fig.22 – Suggested mounting hardware.

TABLE I

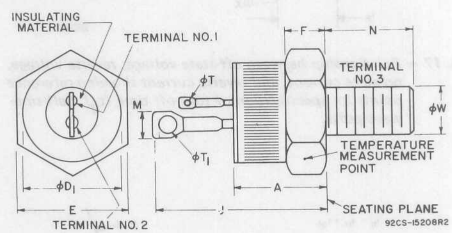
TYPE	MOUNTING ARRANGEMENT	THERMAL RESISTANCE* (Case-to-Heat Sink)
2N3654–2N3658 S7432M	Directly mounted on heat sink (Heat-Sink Compount: Dow Corning 340 silicone heat-sink compound, or equivalent.)	0.9 °C/W
	Mounted on heat sink with a 0.004 to 0.006-in. (0.10 to 0.15-mm) thick mica insulating washer (between unit and heat sink). Without heat-sink compound	2.8 °C/W
	With heat-sink compound. Heat-Sink Compount: Dow Corning 340 silicone heat-sink compound, or equivalent.)	1.8 °C/W

*Normal value. Actual will vary slightly depending on use of heat sink compound, mounting surface, insulator thickness, mounting torque, and etc.

NOTE 1: Dimensions in parentheses are in millimeters and are derived from the basic inch dimensions as indicated.

NOTE 2: The recommended torque is 35 in.-lb. applied to a ¼-28 UNF-2B hex: nut assembled on thread. The applied torque during installation should not exceed 50 in.-lb.

DIMENSIONAL OUTLINE JEDEC TO-48



SYMBOL	INCHES MIN.	INCHES MAX.	MILLIMETERS MIN.	MILLIMETERS MAX.	NOTES
A	0.330	0.505	8.4	12.8	–
φD1	–	0.544	–	13.81	–
E	0.544	0.562	13.82	14.28	–
F	0.113	0.200	2.87	5.08	–
J	0.950	1.100	24.13	27.94	–
M	0.215	0.225	5.46	5.71	–
N	0.422	0.453	10.72	11.50	–
φT	0.058	0.068	1.47	1.73	–
φT1	0.138	0.148	3.51	3.75	–
φW	1/4-28 UNF-2A		1/4-28 UNF-2A		1

NOTES:
1. φW is pitch diameter of coated threads.
REF: Screw-Thread Standards for Federal Services, Handbook H28, Part I. Recommended Torque: 35 inch-pounds.

TERMINAL CONNECTIONS

No. 1 – Gate
No. 2 – Cathode
Case, No. 3 – Anode

Rectifiers

DIFFUSED-JUNCTION SILICON RECTIFIERS

FLANGED-CASE AXIAL-LEAD TYPES

For Power-Supply Applications In Industrial and Military Electronic Equipment

RCA-1N440B, 1N441B, 1N442B, 1N443B, 1N444B, and 1N445B are hermetically sealed silicon rectifiers of the diffused-junction type, designed for use in power supplies of magnetic amplifiers, radio receivers, dc blocking circuits, power supplies, and other military and industrial applications.

These devices have dc forward-current ratings to 0.75 ampere at an ambient temperature of 25°C, and peak reverse voltage ratings of 100, 200, 300, 400, 500 and 600 volts, respectively.

The 1N440B through 1N445B feature (1) sturdy and compact mount structure, (2) axial leads for flexibility of circuit connections, (3) welded hermetic seals—every unit is pressure-tested to assure protection against moisture and contamination, (4) superior junction formation made possible by a diffusion process with very precise controls. In addition, these devices are designed to meet the following stringent environmental, mechanical and life requirements of prime importance in military applications: (a) special temperature-cycling tests to assure stable performance over the entire operating temperature range, (b) special coating to provide protection against the effects of severe environmental conditions,

FEATURES:

- stringent environmental and mechanical tests to insure dependable performance in industrial and military applications
- hermetically sealed JEDEC DO-1 package
- wide operating-temperature range:
  1N440B, 1N441B, 1N442B, 1N443B: -65 to +165°C
  1N444B, 1N445B: -65 to +150°C

RECTIFIER SERVICE

Absolute-Maximum Ratings, for a Supply Frequency of 60 Hz:

	1N440B	1N441B	1N442B	1N443B	1N444B	1N445B	UNITS
PEAK REVERSE VOLTAGE	100	200	300	400	500	600	V
RMS SUPPLY VOLTAGE							
For resistive or inductive loads	70	140	210	280	350	420	V
DC REVERSE (BLOCKING) VOLTAGE	100	200	300	400	500	600	V
FORWARD CURRENT:[a]							
DC:							
at $T_A = 50^oC$	750	750	750	750	650	650	mA
at $T_A = 100^oC$	500	500	500	500	425	400	mA
at $T_A = 150^oC$	250	250	250	250	0	0	mA
Peak, Repetitive	3.5	3.5	3.5	3.5	3.5	3.5	A
Surge, One-Cycle	15	15	15	15	15	15	A
TEMPERATURE RANGE (Ambient):							
Operating	165	165	165	165	150	150	°C
Storage	← -65 to +175 →						°C

[a] For maximum dc forward current values at ambient temperatures other than those specified, See Rating Chart Fig. 1.

Characteristics, at Ambient Temperature (T_A) = 25°C:

CHARACTERISTICS	1N440B	1N441B	1N442B	1N443B	1N444B	1N445B	UNITS
Maximum Forward Voltage Drop (DC) at full load current.	1.5	1.5	1.5	1.5	1.5	1.5	V
Maximum Reverse Current (DC) at maximum peak reverse voltage	0.3	0.75	1	1.5	1.75	2	μA
Maximum Reverse Current (averaged over 1 complete cycle of supply voltage): at maximum rated PRV, T_A = 150°C	100	100	200	200	200	200	μA

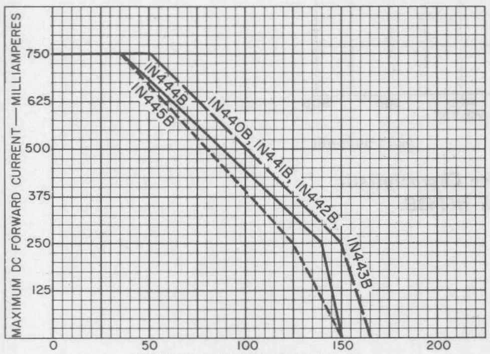


Fig.1 - Rating Chart for RCA-1N440B through 1N445B.

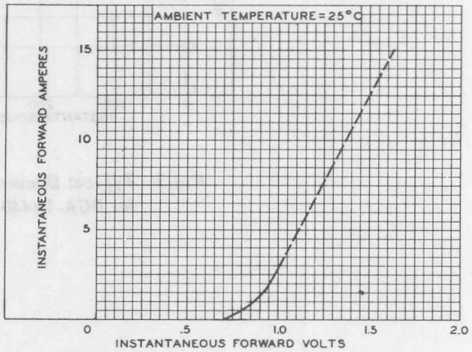


Fig.2 - Typical Forward Voltage and Current Characteristic for RCA-1N440B through 1N445B.

OPERATING CONSIDERATIONS

The *maximum ratings* in the tabulated data are established in accordance with the following definition of the *Absolute-Maximum Rating System* for rating electron devices.

Absolute-Maximum ratings are limiting values of operating and environmental conditions applicable to any electron device of a specified type as defined by its published data, and should not be exceeded under the worst probable conditions.

The device manufacturer chooses these values to provide acceptable serviceability of the device, taking no responsibility for equipment variations, environment variations, and the effects of changes in operating conditions due to variations in device characteristics.

The equipment manufacturer should design so that initially and throughout life no absolute-maximum value for the intended service is exceeded with any device under the worst probable operating conditions with respect to supply-voltage variation, equipment component variation, equipment control adjustment, load variation, signal variation, environmental conditions, and variations in device characteristics.

The *flexible leads* of these rectifiers are usually soldered to the circuit elements. It is desirable in all soldering operations to provide some slack or an expansion elbow in the leads to prevent excessive tension on the leads. It is important during the soldering operation to avoid excessive heat in order to prevent possible damage to the rectifiers. To absorb some of the heat, grip the flexible lead of the rectifier between the case and the soldering point with a pair of pliers.

When dip soldering is employed in the assembly of printed circuitry using these rectifiers, the temperature of the solder should not exceed 255° C for a maximum immersion period of 10 seconds. Furthermore, the leads should not be dip soldered beyond points A and B indicated on the Dimensional Outline Drawing.

Because the metal cases of these rectifiers may operate at voltages which are dangerous, care should be taken in the design of equipment to prevent the operator from coming in contact with the rectifier. It is recommended that these rectifiers be mounted on the underside of the chassis.

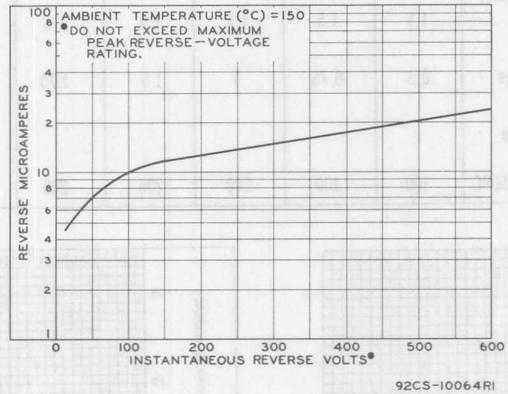
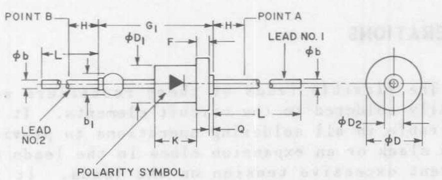


Fig.3 - Typical Dynamic Reverse Characteristic for RCA-1N440B through 1N445B.

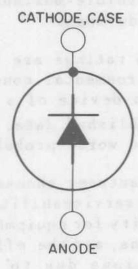
DIMENSIONAL OUTLINE



SYMBOL	INCHES		MILLIMETERS		NOTES
	MIN.	MAX.	MIN.	MAX.	
φb	0.027	0.035	0.69	0.89	2
b_1	–	0.125	–	3.18	1
φD	0.360	0.400	9.14	10.16	
φD_1	0.245	0.280	6.22	7.11	
φD_2	–	0.200	–	5.08	
F	–	0.075	–	1.91	
G_1	–	0.725	–	18.42	
K	0.220	0.260	5.59	6.60	
L	1.000	1.625	25.40	41.28	
Q	–	0.025	–	0.64	
H	0.5	–	12.7	–	

NOTES:

1. Dimension to allow for pinch or seal deformation anywhere along tubulation (optional).
2. Diameter to be controlled from free end of lead to within 0.188 inch (4.78 mm) from the point of attachment to the body. Within the 0.188 inch (4.78 mm) dimension, the diameter may vary to allow for lead finishes and irregularities.



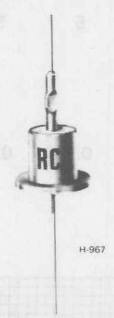
TERMINAL DIAGRAM for Types 1N440B, 1N441B, 1N442B, 1N443B, 1N444B, 1N445B

RCA

Solid State Division

Rectifiers

1N536 1N538 1N540 1N537 1N539 1N547 1N1095



H-967

JEDEC DO-1

Diffused-Junction Silicon Rectifiers

Flanged-Case, Axial-Lead Types
For Power-Supply Applications

Features:

- **Wide operating-temperature range : -65 to +65°C.**
- **Stringent environmental and mechanical tests to insure dependable performance in industrial and military applications.**
- **Peak reverse voltages from 50 to 600 V.**
- **Max. dc forward current = 250 mA at T_A = 150°C.**
- **Hermetically sealed JEDEC DO-1 package.**

RCA-1N536, 1N537, 1N538, 1N539, 1N540, 1N547, and 1N1095 are hermetically sealed silicon rectifiers of the diffused-junction type. They are specifically designed for use in power supplies of industrial and military equipment capable of operating at dc forward currents up to 750 milliamperes and temperatures ranging from -65° to +165°C.

These silicon rectifiers have peak reverse voltage ratings from 50 to 600 volts, and a maximum reverse current of 5 microamperes at rated peak reverse voltage and ambient temperature of 25°C.

These silicon rectifiers are designed to meet such stringent environmental, mechanical, and life requirements of prime importance in military applications as: (1) sturdy and compact mount structure, (2) axial leads for flexibility of circuit connections, (3) welded hermetic seals, and (4) special temperature cycling tests to assure stable performance over the entire operating temperature range.

RECTIFIER SERVICE, ABSOLUTE-MAXIMUM RATINGS, *for a Supply Frequency of 60 Hz:*

	1N536	1N537	1N538	1N539	1N540	1N1095	1N547	
PEAK REVERSE VOLTAGE	50	100	200	300	400	500	600	V
RMS SUPPLY VOLTAGE								
For resistive or inductive loads	35	70	140	210	280	350	420	V
DC REVERSE – (BLOCKING) VOLTAGE	50	100	200	300	400	500	400	V
FORWARD CURRENT*:								
DC, for resistive or inductive loads:								
T_A = 50°C	750	750	750	750	750	750	750	mA
SURGE, one cycle	15	15	15	15	15	15	15	A
OPERATING FREQUENCY	100	100	100	100	100	100	100	kHz
TEMPERATURE RANGE (Ambient):								
Operating	←			-65 to +165			→	°C
Storage	←			-65 to +175			→	°C

*For maximum dc forward current values at ambient temperatures other than those specified, see Rating Chart, Fig. 1.

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	1N536	1N537	1N538	1N539	1N540	1N547	1N1095	
Maximum Forward Voltage Drop (DC) at a load current of 500 mA	1.1	1.1	1.1	1.1	1.1	1.2	1.2	V
Maximum Reverse Current (DC) at maximum peak reverse voltage	5	5	5	5	5	5	5	μA
Maximum Reverse Current (Averaged over 1 complete cycle of supply voltage): at maximum rated PRV, $T_A = 150^oC$	0.4	0.4	0.3	0.3	0.3	0.35	0.3	mA

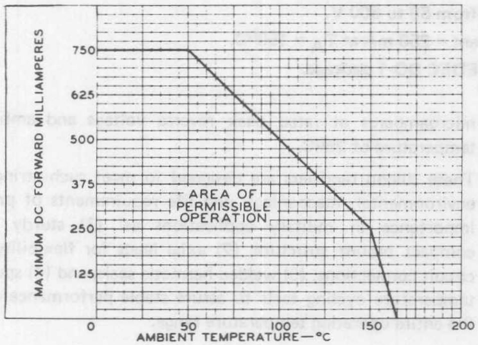


Fig.1— Rating chart.

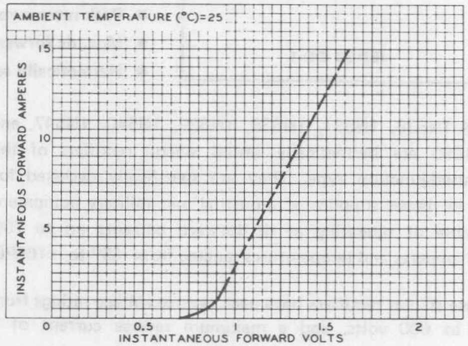


Fig.2— Typical forward voltage and current characteristic.

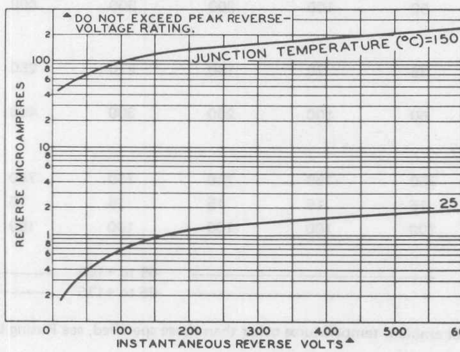
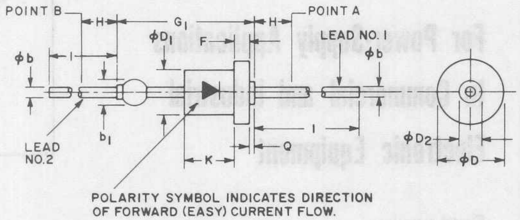


Fig.3— Typical dynamic reverse characteristics.

DIMENSIONAL OUTLINE

JEDEC DO-1



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SYMBOL	INCHES		MILLIMETERS		NOTES
	MIN.	MAX.	MIN.	MAX.	
ϕb	0.027	0.035	0.69	0.89	2
b_1		0.125		3.18	1
ϕD	0.360	0.400	9.14	10.16	
ϕD_1	0.245	0.280	6.22	7.11	
ϕD_2		0.200		5.08	
F		0.075		1.91	
G_1		0.725		18.42	
K	0.220	0.260	5.59	6.60	
l	1.000	1.625	25.40	41.28	
Q		0.025		0.64	
H	0.5		12.7		

NOTES:

1. Dimension to allow for pinch or seal deformation anywhere along tubulation (optional).
2. Diameter to be controlled from free end of lead to within 0.188 inch (4.78 mm) from the point of attachment to the body. Within the 0.188 inch (4.78 mm) dimension, the diameter may vary to allow for lead finishes and irregularities.

TERMINAL CONNECTIONS

Lead No. 1 & Case — Cathode
Lead No. 2 — Anode

RCA Solid State Division

Rectifiers
1N1763A
1N1764A

RCA-1N1763A and 1N1764A are hermetically sealed silicon rectifiers of the diffused-junction type, designed for use in power supplies of color and black-and-white television receivers, radio receivers, phonographs, high-fidelity amplifier systems, and other electronic equipment for commercial and industrial applications.

RCA-1N1763A and 1N1764A supersede and are unilaterally interchangeable with RCA-1N1763 and 1N1764, respectively. The new rectifiers incorporate all of the superior performance and reliability features which have gained industry acceptance for their RCA prototypes, and, in addition, offer substantially higher dc-output-current capabilities, lower reverse (leakage) currents, lower forward voltage drop, and a wider operating-temperature range.

Both devices have dc forward-current ratings of 1 ampere — resistive or inductive load, and 0.75 ampere — capacitive load at free-air temperatures up to 75°C (natural convection cooling). They can provide dc output currents of up to 2 amperes to capacitive loads when attached to simple heat sinks.

RCA-1N1763A has a peak-reverse-voltage rating of 400 volts, and is intended for applications in which the rectifier operates directly from an ac power line supplying up to 140 volts rms for capacitive loads, or up to 280 volts rms for resistive or inductive loads.

RCA-1N1764A has a peak-reverse-voltage rating of 500 volts, and is intended for applications in which the rectifier operates from an ac line through a step-up transformer supplying up to 175 volts rms for capacitive loads, or up to 350 volts rms for resistive or inductive loads.

RCA-1N1763A and 1N1764A have an operating-temperature range of -65°C to +135°C. They utilize the JEDEC DO-1 flanged-case, axial-lead package which provides flexibility of installation in both hand-wired and printed-circuit equipment designs. These new rectifiers, like their RCA prototypes, are conservatively rated and incorporate the following design features: (1) welded, hermetically sealed case for protection against moisture and contamination; (2) superior junction characteristics made possible by a precisely controlled diffusion process; (3) extensive and rigorous quality-control procedures.

DIFFUSED-JUNCTION SILICON RECTIFIERS

Flanged-Case Axial-Lead Types

For Power-Supply Applications In Commercial and Industrial Electronic Equipment

Features:

- high dc-output-current capability:
  - a) with natural convection cooling:
    - 1 ampere - resistive or inductive load; 3/4 ampere - capacitive load } to 75°C T_{FA}
  - b) with simple heat sinks:
    - 2 amperes - capacitive load } to 105°C T_C
    - up to 2 amperes - capacitive load } to 75°C T_{FA}
- low dc reverse (leakage) currents: 5 μa max. at 25°C; 100 μa max. at 75°C
- low forward voltage drop: 1.2 volts max. at a dc forward current of 1 ampere
- wide operating-temperature range: -65°C to +135°C
- hermetically sealed JEDEC DO-1 package
- unilaterally interchangeable with Types 1N1763 and 1N1764

RECTIFIER SERVICE

Absolute-Maximum Ratings, *for a Supply Frequency of 60 cps:*

	Type 1N1763A		Type 1N1764A		
PEAK REVERSE VOLTAGE	400		500		max. volts
RMS SUPPLY VOLTAGE:					
For operation with resistive or inductive loads	280		350		max. volts
For operation with capacitive loads	140		175		max. volts
	At Free-Air Temperatures		*At Free-Air Temperatures*		
	Up to 75°C	*Above 75°C*	*Up to 75°C*	*Above 75°C*	
FORWARD CURRENT:					
For operation with resistive or inductive loads:					
AVERAGE (DC)	1	See *Fig.1*	1	See *Fig.1*	max. amp
For operation with capacitive loads:					
AVERAGE (DC)	0.75	See *Fig.1*	0.75	See *Fig.1*	max. amp
PEAK RECURRENT	5	See *Fig.1*	5	See *Fig.1*	max. amp
SURGE, for "turn-on" transient of 2 milliseconds duration	35	See *Fig.1*	35	See *Fig.1*	max. amp
TEMPERATURE RANGE (FREE-AIR):					
Operating	-65 to +135		-65 to +135		°C
Storage	-65 to +150		-65 to +150		°C

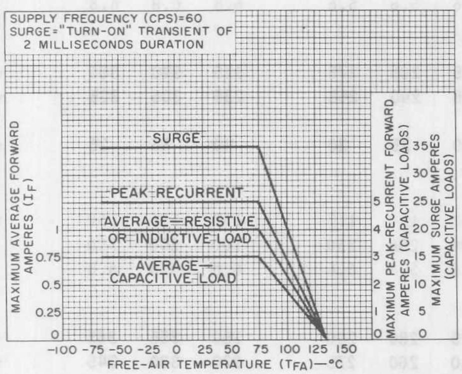


Fig.1 - Rating Chart for RCA-1N1763A and 1N1764A

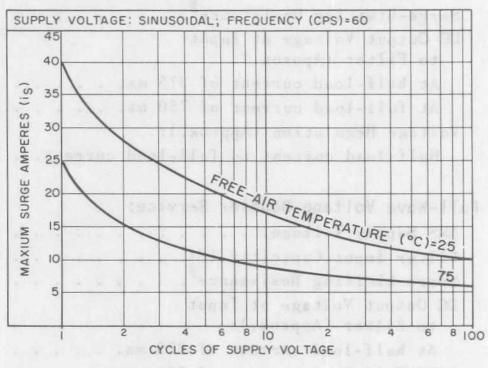


Fig.2 - Repetitive Surge Current Rating Chart for RCA-1N1763A and 1N1764A

Maximum DC Reverse Current;			
At a Peak Reverse Voltage of 400 volts	5	-	μa
At a Peak Reverse Voltage of 500 volts	-	5	μa

Characteristics, *at a Free-Air Temperature of 75°C:*

Maximum DC Reverse Current:			
At a Peak Reverse Voltage of 400 volts	0.1	-	ma
At a Peak Reverse Voltage of 500 volts	-	0.1	ma

Typical Performance Characteristics, *at a Free-Air Temperature of 25°C:*

	Type 1N1763A			Type 1N1764A			
Half-Wave Rectifier Service:							
RMS Supply Voltage	117	117	117	150	150	150	volts
Filter-Input Capacitor (C)	100	200	350	100	200	350	μF
Surge-Limiting Resistance#	5.6	5.6	5.6	6.8	6.8	6.8	ohms
DC Output Voltage at Input to Filter (Approx.):							
At half-load current of 375 ma.	140	145	150	180	185	190	volts
At full-load current of 750 ma.	125	130	140	155	160	170	volts
Voltage Regulation (Approx.):							
Half-load current to full-load current	15	15	10	25	25	20	volts
Half-Wave Voltage-Doubler Service:							
RMS Supply Voltage	117	117	117	150	150	150	volts
Filter-Input Capacitor (C)	100	200	350	100	200	350	μF
Surge-Limiting Resistance#	5.6	5.6	5.6	6.8	6.8	6.8	ohms
DC Output Voltage at Input to Filter (Approx.):							
At half-load current of 375 ma.	255	265	275	325	340	350	volts
At full-load current of 750 ma.	225	240	255	285	305	325	volts
Voltage Regulation (Approx.):							
Half-load current to full-load current	30	25	20	40	35	25	volts
Full-Wave Voltage-Doubler Service:							
RMS Supply Voltage	117	117	117	150	150	150	volts
Filter Input Capacitor (C)	100	200	350	100	200	350	μF
Surge-Limiting Resistance#	5.6	5.6	5.6	6.8	6.8	6.8	ohms
DC Output Voltage at Input to Filter (Approx.):							
At half-load current of 375 ma.	275	280	290	350	355	365	volts
At full-load current of 750 ma.	250	260	275	320	330	345	volts
Voltage Regulation (Approx.):							
Half-load current to full-load current	25	20	15	30	25	20	volts

The transformer series resistance or other resistance in the rectifier supply circuit may be deducted from the value shown.

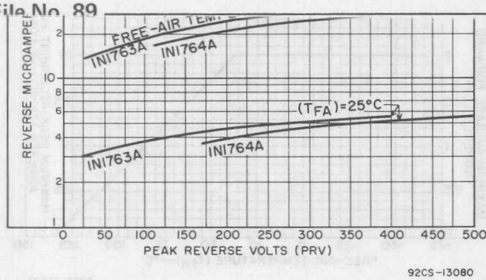


Fig.3 - Typical Dynamic Reverse Current Characteristics for RCA-1N1763A and 1N1764A.

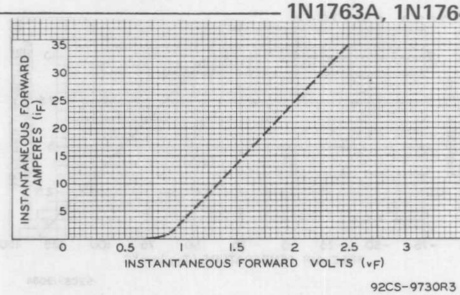


Fig.4 - Typical Forward Voltage and Current Characteristics for RCA-1N1763A and 1N1764A.

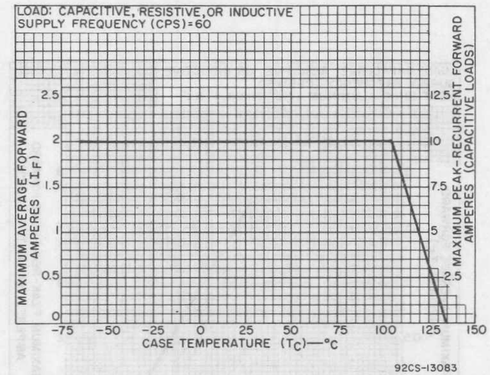
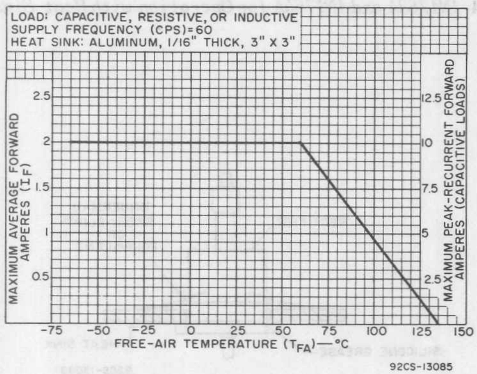
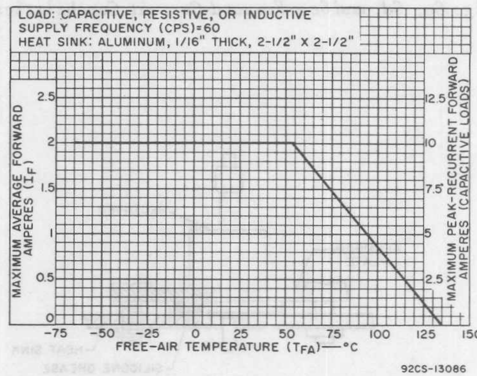


Fig.5 - Forward-Current Capabilities of RCA-1N1763A and 1N1764A for Operation with Heat Sink at Case Temperatures from -65°C to +135°C.

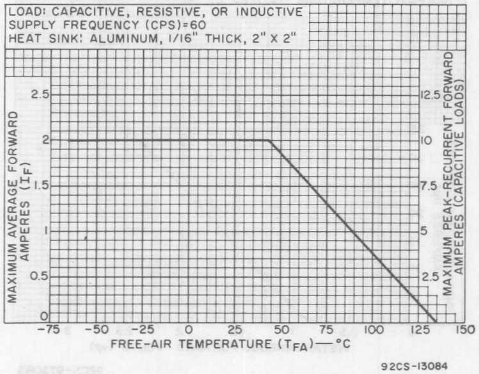


a) 3" x 3" Heat Sink.

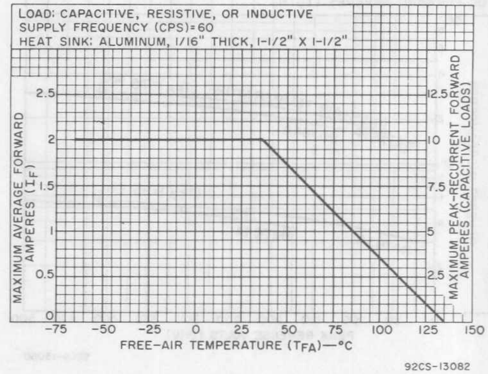


b) 2-1/2" x 2-1/2" Heat Sink.

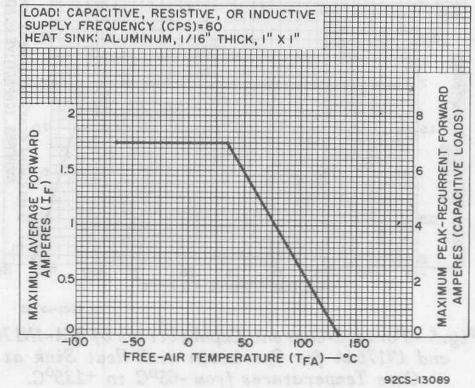
Figs.6a and 6b - Forward-Current Capabilities of RCA-1N1763A and 1N1764A for Operation with Heat Sinks.



c) 2" x 2" Heat Sink.

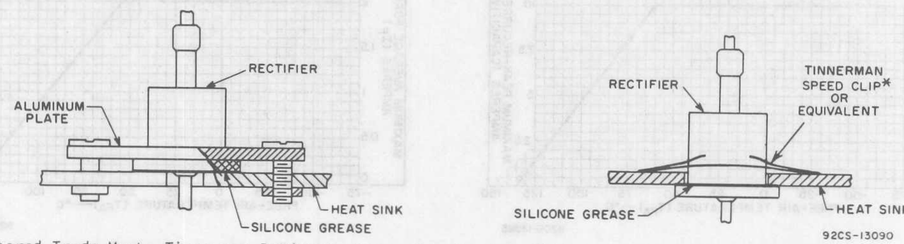


d) 1-1/2" x 1-1/2" Heat Sink.



e) 1" x 1" Heat Sink.

Figs.6c, 6d, and 6e - Forward-Current Capabilities of RCA-1N1763A and 1N1764A for Operation with Heat Sinks.



* Registered Trade Mark, Tinnerman Products, Inc., Cleveland 1, Ohio.

Fig.7 - Suggested Methods for Attaching RCA-1N1763A 1N1764A to Heat Sink

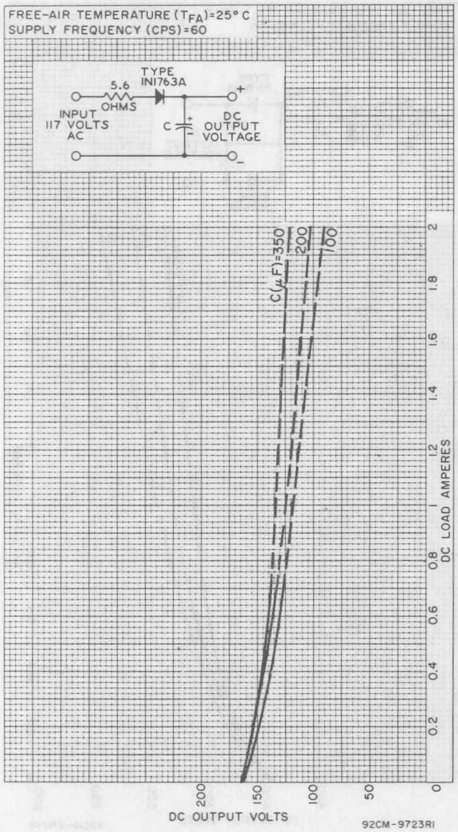


Fig.8 - Typical Operation Characteristics for RCA-1N1763A in Half-Wave Rectifier Service.

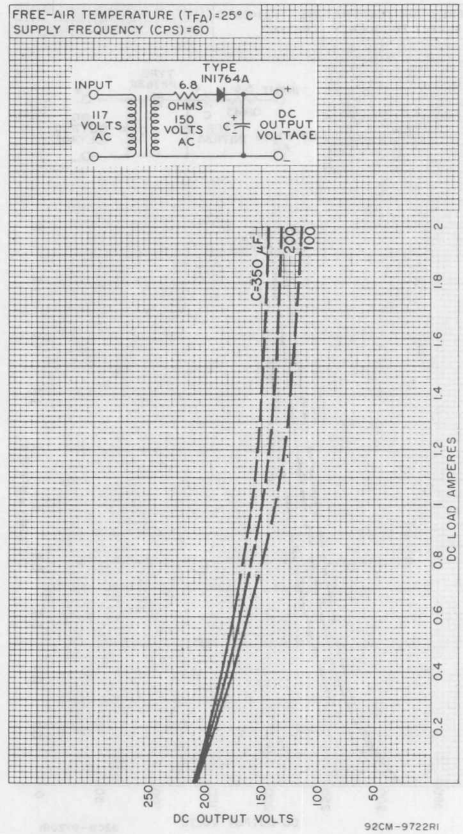


Fig.9 - Typical Operation Characteristics for RCA-1N1764A in Half-Wave Rectifier Service.

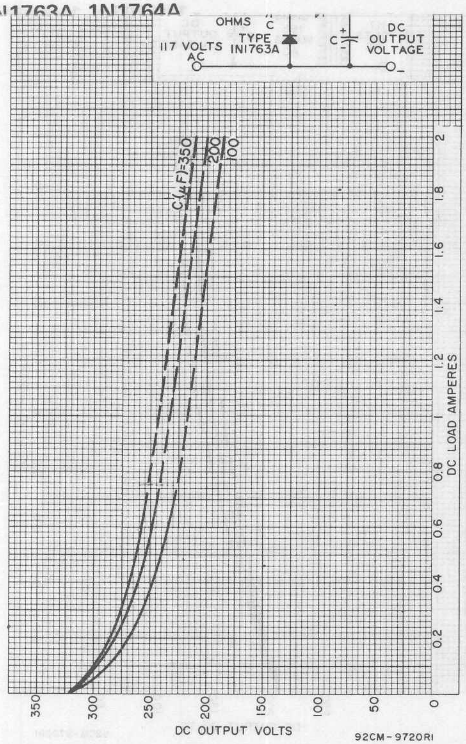


Fig. 10 - Typical Operation Characteristics of RCA-1N1763A in Half-Wave Voltage-Doubler Service.

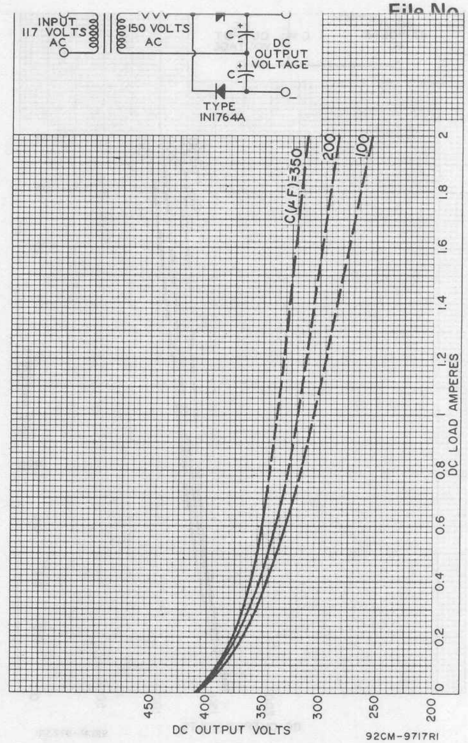
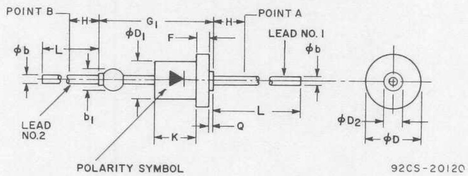


Fig. 11 - Typical Operation Characteristics of RCA-1N1764A in Full-Wave Voltage-Doubler Service.

DIMENSIONAL OUTLINE (JEDEC DO-1)



SYMBOL	INCHES		MILLIMETERS		NOTES
	MIN.	MAX.	MIN.	MAX.	
ϕb	0.027	0.035	0.69	0.89	2
b_1	–	0.125	–	3.18	1
ϕD	0.360	0.400	9.14	10.16	
ϕD_1	0.245	0.280	6.22	7.11	
ϕD_2	–	0.200	–	5.08	
F	–	0.075	–	1.91	
G_1	–	0.725	–	18.42	
K	0.220	0.260	5.59	6.60	
L	1.000	1.625	25.40	41.28	
Q	–	0.025	–	0.64	
H	0.5	–	12.7	–	

NOTES:

1. Dimension to allow for pinch or seal deformation anywhere along tubulation (optional).
2. Diameter to be controlled from free end of lead to within 0.188 inch (4.78 mm) from the point of attachment to the body. Within the 0.188 inch (4.78 mm) dimension, the diameter may vary to allow for lead finishes and irregularities.

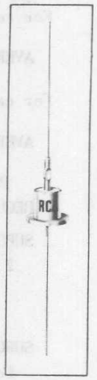
RCA Solid State Division

Rectifiers

1N2858A 1N2859A 1N2860A 1N2861A 1N2862A 1N2863A 1N2864A

DIFFUSED-JUNCTION SILICON RECTIFIERS

Flanged-Case Axial-Lead Types For General-Purpose Applications In Industrial And Commercial Electronic Equipment



RCA-1N2858A, 1N2859A, 1N2860A, 1N2861A, 1N2862A, 1N2863A, and 1N2864A are hermetically sealed silicon rectifiers of the diffused-junction type, designed for use in a variety of applications in industrial and commercial electronic equipment.

RCA-1N2858A through 1N2864A supersede and are unilaterally interchangeable with RCA-1N2858 through 1N2864, respectively. The new rectifiers incorporate all of the superior performance and reliability features which have gained industry acceptance for their RCA prototypes, and, in addition, offer substantially higher dc output-current capabilities, lower reverse (leakage) currents, and a wider operating-temperature range.

All seven of these new rectifier types have maximum dc-forward-current ratings of 1 ampere for resistive or inductive loads and 0.75 ampere for capacitive loads at free-air temperatures up to 75°C (natural convection cooling). They are also capable of providing dc output currents of up to 2 amperes with capacitive loads when attached to simple heat sinks.

RCA-1N2858A through 1N2864A differ only in peak-reverse-voltage ratings (see Maximum Ratings chart). They are rated for operation at free-air temperatures from -65° to +135°C, and utilize the JEDEC DO-1 flange-type, axial-lead rectifier package which provides flexibility of installation in both hand-wired and printed-circuit equipment designs.

These new rectifiers, like their RCA prototypes, are conservatively rated, and incorporate the following design features and special tests which contribute to their outstanding performance and reliability: (1) junctions of extremely high uniformity produced by a special, precisely controlled diffusion process, (2) rugged internal mount structure, (3) hermetically sealed cases, (4) prolonged treatment at high temperatures to stabilize characteristics, (5) pressure tests of seals for protection against moisture and contamination, (6) tests for forward and reverse characteristics at 25°C, and (7) high-temperature dynamic tests under full-load conditions.

Features:

- high dc-output-current capability:
  - 1 ampere - resistive or inductive load; 3/4 ampere - capacitive load — to 75°C with natural convection cooling
  - up to 2 amperes - capacitive load — to 105°C with simple heat sinks
- low dynamic reverse current:
  0.1 ma max. at 50°C
  0.3 ma max. at 75°C
- low dc forward voltage drop:
  1.2 volts max. at 25°C with 1 ampere dc forward current
- wide operating-temperature range:
  -65° to +135°C
- hermetically sealed JEDEC DO-1 package
- unilaterally interchangeable with Types 1N2858 through 1N2864
- specially processed and tested for high reliability and stability of characteristics

RECTIFIER SERVICE

Absolute-Maximum Ratings, *for a Supply Frequency of 60 cps:*

	1N2858A	1N2859A	1N2860A	1N2861A	1N2862A	1N2863A	1N2864A	
PEAK REVERSE VOLTAGE.	50	100	200	300	400	500	600	max. volts
RMS SUPPLY VOLTAGE:								
For resistive or inductive loads. . . .	35	70	140	210	280	350	420	max. volts
For capacitive loads.	17	35	70	105	140	175	210	max. volts
DC REVERSE (BLOCKING) VOLTAGE	50	100	200	300	400	500	600	max. volts
FORWARD CURRENT:								
For resistive or inductive loads:								
AVERAGE (DC) At T_{FA} up to 75°C. . . .	1	1	1	1	1	1	1	max. amp
AVERAGE (DC) At T_{FA} above 75°C. . . .	← See *Fig.1* →							
For capacitive loads:								
AVERAGE (DC) At T_{FA} up to 75°C. . . .	0.75	0.75	0.75	0.75	0.75	0.75	0.75	max. amp
AVERAGE (DC) At T_{FA} above 75°C. . . .	← See *Fig.1* →							
PEAK RECURRENT At T_{FA} up to 75°C. . . .	5	5	5	5	5	5	5	max. amp
PEAK RECURRENT At T_{FA} above 75°C. . . .	← See *Fig.1* →							
SURGE, for "turn-on" transient of 2 milliseconds duration:								
At T_{FA} up to 75°C. . . .	35	35	35	35	35	35	35	max. amp
At T_{FA} above 75°C. . . .	← See *Fig.1* →							
SURGE, repetitive, at T_{FA} = 25°C:								
For one cycle of supply voltage . .	40	40	40	40	40	40	40	max. amp
For more than one cycle of supply voltage.	← See *Fig.2* →							
TEMPERATURE RANGE (FREE-AIR)								
Operating	← -65 to +135 →							°C
Storage	← -65 to +150 →							°C

Characteristics:

	1N2858A	1N2859A	1N2860A	1N2861A	1N2862A	1N2863A	1N2864A	
Maximum Forward Voltage Drop (DC) at I_F = 1 Ampere, T_{FA} = 25°C. . .	1.2	1.2	1.2	1.2	1.2	1.2	1.2	volts
Maximum Dynamic Reverse Current (Averaged over 1 Complete Cycle of Supply Voltage): at Maximum Rated PRV:								
T_{FA} = 50°C. . .	0.1	0.1	0.1	0.1	0.1	0.1	0.1	ma
T_{FA} = 75°C	0.3	0.3	0.3	0.3	0.3	0.3	0.3	ma

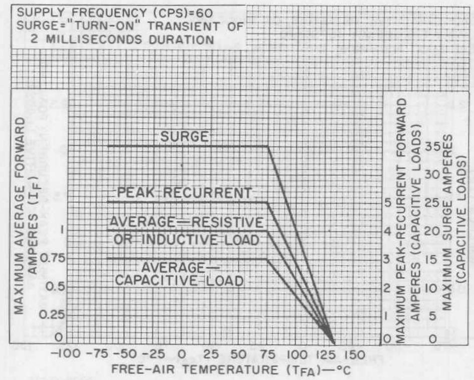


Fig. 1 - Rating Chart for RCA-1N2858A through 1N2864A.

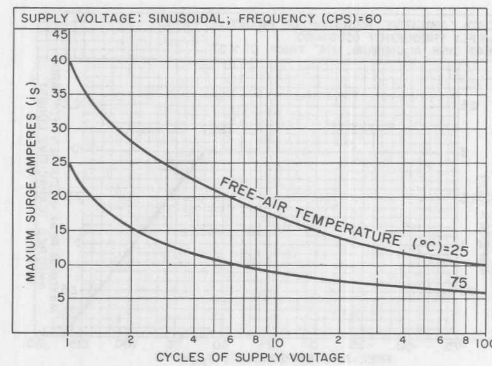


Fig. 2 - Repetitive Surge Current Rating Chart for RCA-1N2858A through 1N2864A.

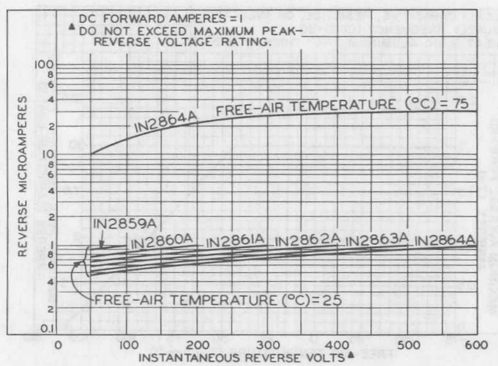


Fig. 3 - Typical Dynamic Reverse Characteristics for RCA-1N2858A through 1N2864A.

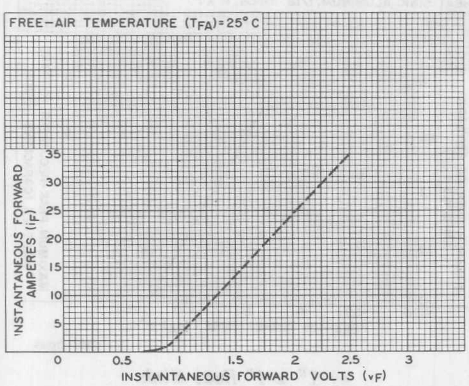


Fig. 4 - Typical Forward Voltage and Current Characteristic for RCA-1N2858A through 1N2864A.

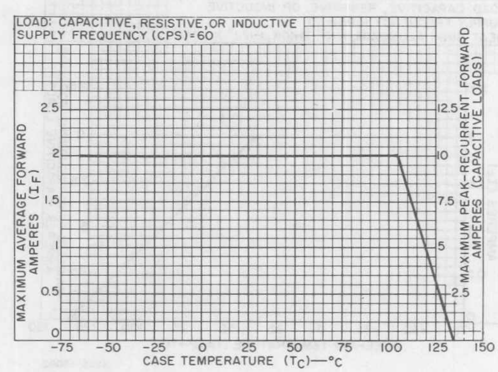
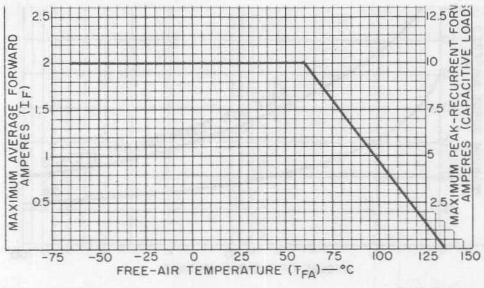
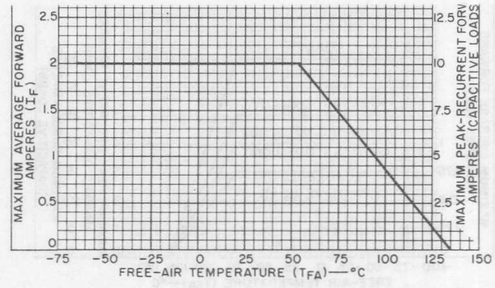


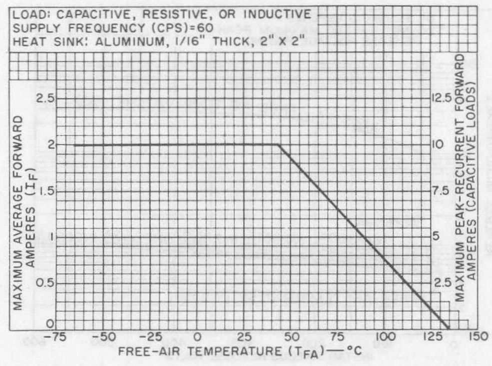
Fig. 5 - Forward-Current Capabilities of RCA-1N2858A through 1N2864A for Operation with Heat Sink at Case Temperatures from -65°C to +135°C.



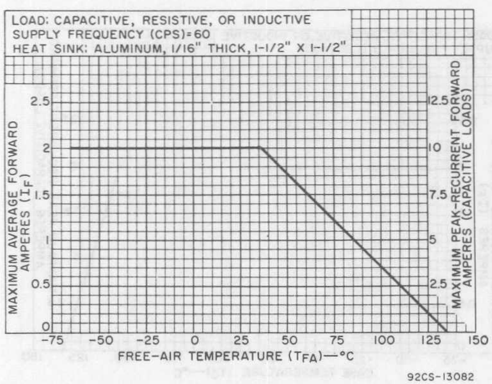
a) 3" x 3" Heat Sink.



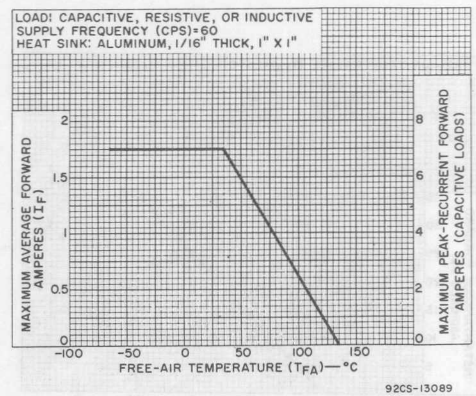
b) 2-1/2" x 2-1/2" Heat Sink.



c) 2" x 2" Heat Sink.

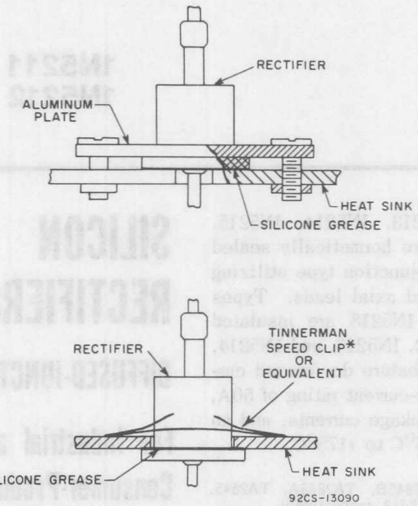


d) 1-1/2" x 1-1/2" Heat Sink.



e) 1" x 1" Heat Sink.

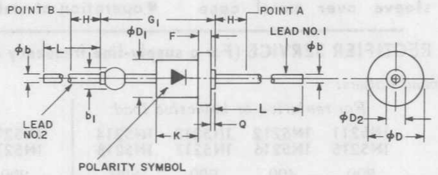
Figs. 6a, 6b, 6c, 6d, and 6e - Forward-Current Capabilities of RCA-1N2858A through 1N2864A for Operation with Heat Sinks.



* Registered Trade Mark, Tinneman Products, Inc., Cleveland 1, Ohio.

Fig. 7 - Suggested Methods for Attaching RCA-1N2858A through 1N2864A to Heat Sink.

DIMENSIONAL OUTLINE (JEDEC-DO-1) FOR RCA-1N2858A through 1N2864A



SYMBOL	INCHES		MILLIMETERS		NOTES
	MIN.	MAX.	MIN.	MAX.	
ϕb	0.027	0.035	0.69	0.89	2
b_1	–	0.125	–	3.18	1
ϕD	0.360	0.400	9.14	10.16	
ϕD_1	0.245	0.280	6.22	7.11	
ϕD_2	–	0.200	–	5.08	
F	–	0.075	–	1.91	
G_1	–	0.725	–	18.42	
K	0.220	0.260	5.59	6.60	
L	1.000	1.625	25.40	41.28	
Q	–	0.025	–	0.64	
H	0.5	–	12.7	–	

NOTES:

1. Dimension to allow for pinch or seal deformation anywhere along tubulation (optional).
2. Diameter to be controlled from free end of lead to within 0.188 inch (4.78 mm) from the point of attachment to the body. Within the 0.188 inch (4.78 mm) dimension, the diameter may vary to allow for lead finishes and irregularities.

TERMINAL CONNECTIONS

Lead No.1 & Case — Cathode
Lead No.2 — Anode

RCA

Solid State Division

Rectifiers

1N5211 1N5212 1N5213 1N5214 1N5215 1N5216 1N5217 1N5218

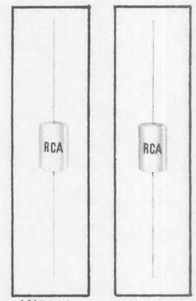
RCA-1N5211, 1N5212, 1N5213, 1N5214, 1N5215, 1N5216, 1N5217, and 1N5218* are hermetically sealed silicon rectifiers of the diffused-junction type utilizing small cylindrical metal cases and axial leads. Types 1N5215, 1N5216, 1N5217, and 1N5218 are insulated versions of types 1N5211, 1N5212, 1N5213, and 1N5214, respectively. These rectifiers feature dc forward current ratings of up to 1 A, a surge-current rating of 50A, low forward voltage drop, low leakage currents, and an operating-temperature range of -65°C to +175°C.

* Formerly Dev. Nos. TA2845C, TA2845B, TA2845A, TA2845, TA7048C, TA7048B, TA7048A, and TA7048, respectively.

SILICON RECTIFIERS

DIFFUSED-JUNCTION TYPES

For Industrial and Consumer-Product Applications



1N5211 through 1N5214 | 1N5215 through 1N5218

- cylindrical design with axial leads for simple handling and installation
- compact, hermetically sealed metal case (0.405" max. length; 0.240" max. dia.)
- types 1N5215 through 1N5218 have transparent, high-dielectric-strength plastic sleeve over metal case
- high maximum forward-current ratings — up to 1 ampere DC at 75°C
- peak-reverse-voltage ratings from 200 to 800 volts
- operation at ambient temperatures to +175°C

RECTIFIER SERVICE (For a supply-line frequency of 60 Hz)

Maximum Ratings, *Absolute-Maximum Values:*

	For resistive or inductive load				*For capacitor-input filter*					
	1N5211 1N5215	1N5212 1N5216	1N5213 1N5217	1N5214 1N5218	1N5211 1N5215	1N5212 1N5216	1N5213 1N5217	1N5214 1N5218		
PEAK REVERSE VOLTAGE	200	400	600	800	200	400	600	800	max.	V
RMS SUPPLY VOLTAGE	140	280	420	560	70	140	210	280	max.	V
FORWARD CURRENT: For ambient temperatures up to 75°C. For ambient temperatures above 75°C, see Rating Chart.										
DC	1	1	1	0.75	0.75	0.75	0.75	0.6	max.	A
PEAK RECURRENT	-	-	-	-	6	6	6	5	max.	A
SURGE — For "turn-on" time of 2 milliseconds	-	-	-	-	50	50	50	50	max.	A
AMBIENT-TEMPERATURE RANGE:										
Operating	-65 to +175									°C
Storage	-65 to +175									°C
LEAD TEMPERATURE: For 10 seconds maximum	255								max.	°C

Characteristics:

	1N5211 1N5215	1N5212 1N5216	1N5213 1N5217	1N5214 1N5218		
Maximum Instantaneous Forward Voltage Drop at dc forward current of 1 ampere and $T_A \leq 75^{\circ}C$	1.2	1.2	1.2	1.2	max.	V
Maximum Reverse Current:						
Dynamic, at $T_A = 75^{\circ}C$**	0.2	0.2	0.2	0.2	max.	mA
Static, at $T_A = 25^{\circ}C$***	0.005	0.005	0.005	0.005	max.	mA

**At max. peak reverse voltage and max. dc forward current. ***At max. peak reverse voltage and zero forward current.

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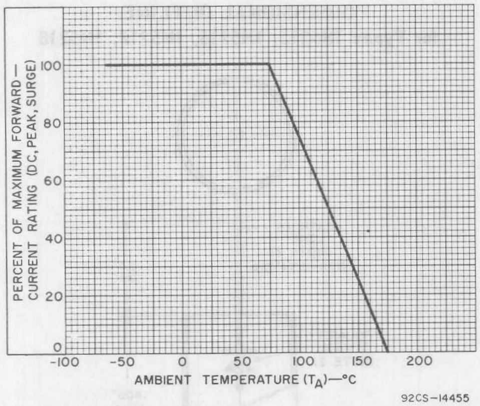


Fig.1 - Rating Chart for Types 1N5211 through 1N5218.

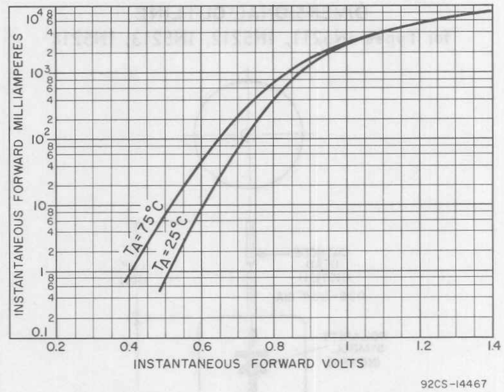


Fig.2 - Typical Forward Characteristics for Types 1N5211 through 1N5218.

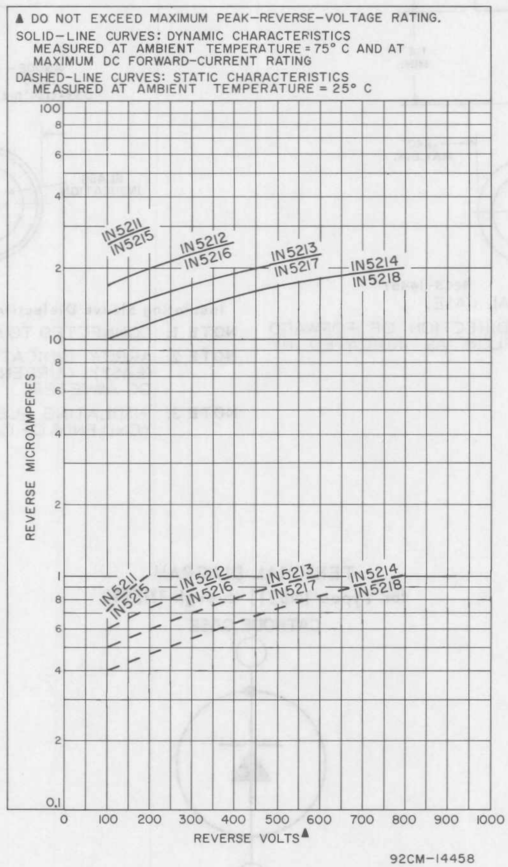
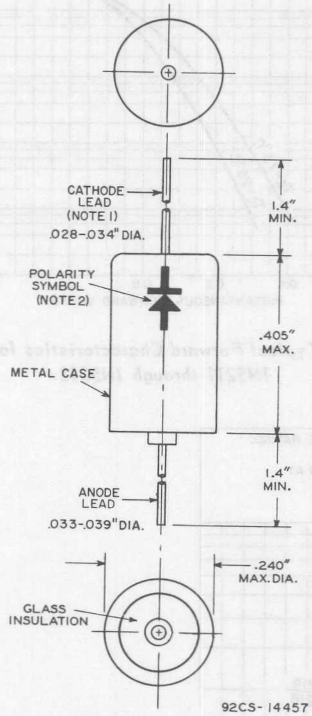


Fig.3 - Typical Reverse Characteristics for Types 1N5211 through 1N5218.

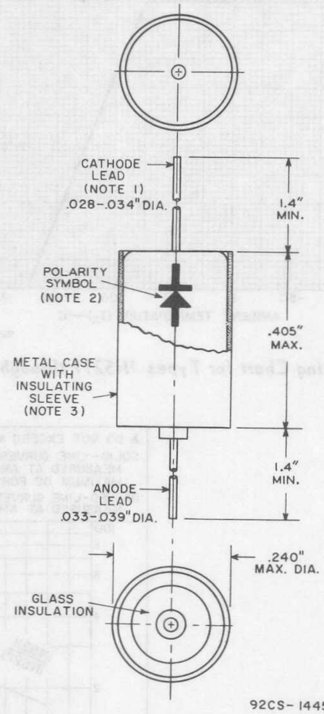
DIMENSIONAL OUTLINE
for Types 1N5211, 1N5212, 1N5213, 1N5214



NOTE 1: CONNECTED TO METAL CASE.

NOTE 2: ARROW INDICATES DIRECTION OF FORWARD (EASY) CURRENT FLOW AS INDICATED BY DC AMMETER.

DIMENSIONAL OUTLINE
for Types 1N5215, 1N5216, 1N5217, 1N5218



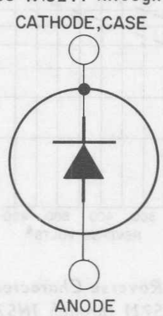
Insulating Sleeve Dielectric Strength: 2000 Volts Minimum

NOTE 1: CONNECTED TO METAL CASE.

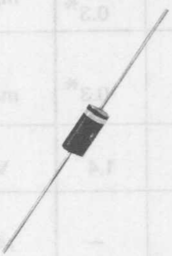
NOTE 2: ARROW INDICATES DIRECTION OF FORWARD (EASY) CURRENT FLOW AS INDICATED BY DC AMMETER.

NOTE 3: INSULATING SLEEVE MAY EXTEND 1/16" BEYOND ENDS OF CASE.

TERMINAL DIAGRAM
for Types 1N5211 through 1N5218



JEDEC DO-15



1N5391–1N5399

H-1695

1.5-A, 50–1000-V Silicon Rectifiers

Plastic-Packaged, General-Purpose Types for Low-Power Applications

Features:

- **High surge-current capability**
- **Low junction-to-lead thermal impedances**
- **−65 to +170° operating temperature range**

RCA-1N5391--1N5399, inclusive, are diffused-junction type silicon rectifiers in an axial-lead plastic package. These devices differ only in their voltage ratings.

Their small size and plastic package of high insulation resistance make these rectifiers especially suitable for those applications in which high packaging densities are employed.

MAXIMUM RATINGS, *Absolute-Maximum Values:*

		1N5391	1N5392	1N5393	1N5394	1N5395	1N5396	1N5397	1N5398	1N5399	
REVERSE VOLTAGE:											
* REPETITIVE PEAK■	V_{RRM}	50	100	200	300	400	500	600	800	1000	V
* NON-REPETITIVE PEAK▼	V_{RSM}	100	200	300	400	525	650	800	1000	1200	V
* WORKING PEAK▲	V_{RWM}	50	100	200	300	400	500	600	800	1000	V
* DC BLOCKING (At T_A = 150°C)	V_R	50	100	200	300	400	500	600	800	1000	V
RMS	$V_{R(RMS)}$	35	70	140	210	280	350	420	560	700	V

FORWARD CURRENT:

		All Types	
* AVERAGE RECTIFIED .... Single-phase, half-wave operation with 60-Hz sinusoidal voltage and resistive load, and 1/2-inch leads; for other lead lengths, see Fig. 1. T_A = 70°C	I_o	1.5	A
* PEAK SURGE	I_{FSM}		
For one-half cycle of applied voltage, 50 Hz (10 ms)		45	A
* 60 Hz (8.3 ms)		50	A
400 Hz (1.25 ms), T_A = 70°C		100	A
For other durations		See Fig. 4.	
TEMPERATURE RANGE:			
* Storage		−65 to +175	°C
* Operating		−65 to +170	°C
***LEAD TEMPERATURE (During Soldering):**			
Measured 1/8 inch from case for 10 s max.		240	°C

■ For single-phase, half-wave sinusoidal pulse of 100-μs duration with a repetition rate of 60 pulses per second.
▼ For one single-phase, half-wave, 60-Hz sinusoidal pulse with this peak value.
▲ Maximum input-voltage rating that can be continuously applied (with the maximum current rating) over the normal operating temperature range|. For single-phase, half-wave operation with a 60-Hz sinusoidal supply and a resistive load.
* In accordance with JEDEC registration format JS-1 RDF-3.

ELECTRICAL CHARACTERISTICS

CHARACTERISTIC	SYMBOL	LIMITS All Types Min.	Typ.	Max.	UNITS
Reverse Current:					
**Static*					
For V_R = rated value & T_J = 25°C	I_R	–	0.001	0.01*	mA
For V_R = rated value & T_J = 150°C			0.100	0.3*	
**Dynamic*					
Full-cycle average, for V_{RWM} = rated value, I_o = 1.5A, T_A = 70°C	$I_{R(AV)}$	–	0.080	0.3*	mA
***Instantaneous Forward-Voltage Drop:**					
At i_F = 1.5A, T_A = 70°C, see Fig. 3.	v_F	–	1.1	1.4*	V
Reverse-Recovery Time:					
At I_{FM} = 30A, pulse duration = 3.1 μs, T_A = 25°C (See Fig. 7; for other conditions, see Fig. 8.)	t_{rr}	–	1.5	–	μs
***Thermal Impedance:**					
Steady-State					
Junction-to-anode-lead	$\theta_{J\text{-}L_a}$	–	–	100	°C/W
Junction-to-cathode-lead	$\theta_{J\text{-}L_k}$	–	–	100	
Anode-Lead } Free convection cooling	–	–	–	148	°C/W/in
Cathode-Lead } Free convection cooling	–	–	–	148	
Transient					
Heat-sink mounting with 0-to-1¼″ leads, and with a pulse duration of 0.6 s. For other pulse durations, see Fig. 6.	$\theta_{J\text{-}HS(t)}$	–	10	–	°C/W

* In accordance with JEDEC registration data format JS-1 RDF-3

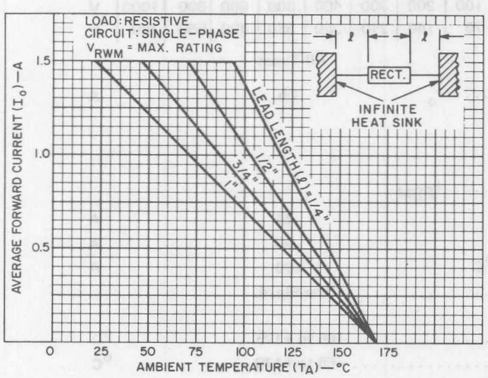


Fig. 1 - Average-forward-current derating curves for types 1N5391–1N5399 for several lead lengths.

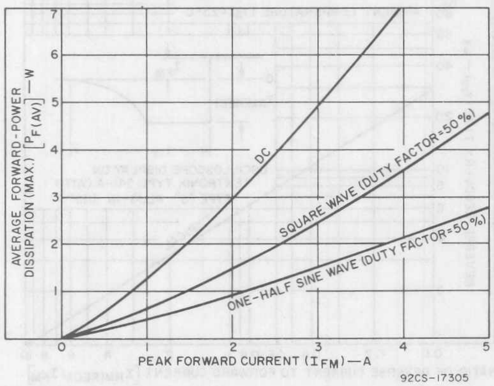


Fig. 2 - Variation of peak forward-power dissipation with peak forward current.

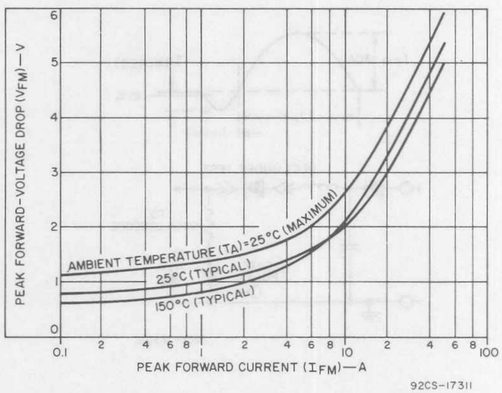


Fig. 3 - Peak forward-voltage drop vs. peak forward current for types 1N5391–1N5399.

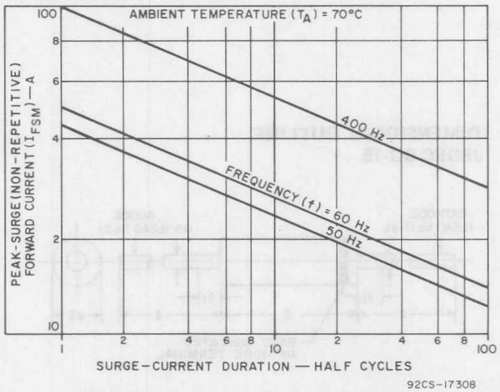


Fig. 4 - Peak-surge (non-repetitive) forward current vs. surge-current duration for types 1N5391–1N5399.

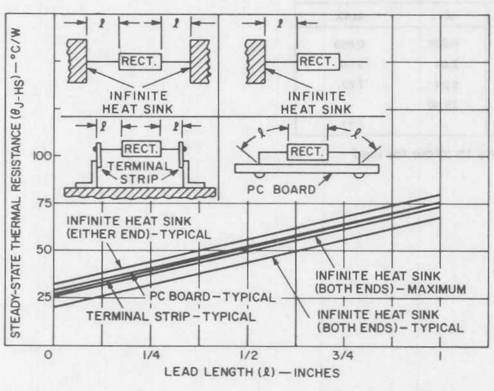


Fig. 5 - Variation of steady-state thermal resistance with lead length (for different mounting methods) for types 1N5391-- 1N5399.

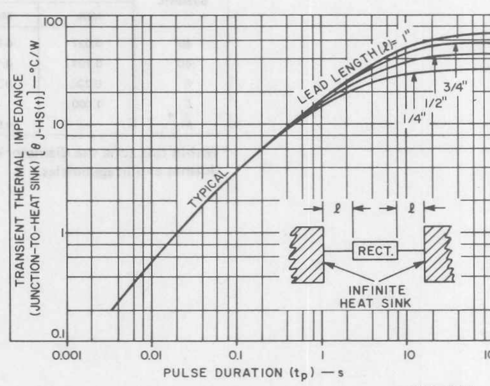


Fig. 6 - Variation of transient thermal impedance with pulse duration for several lead lengths for types 1N5391--1N5399.

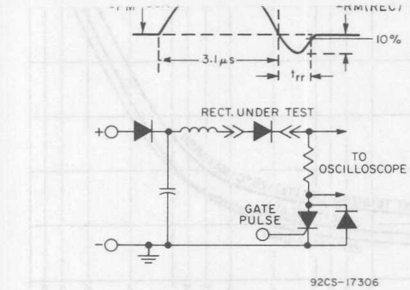


Fig. 7 - Oscilloscope display & test circuit for measurement of reverse-recovery time.

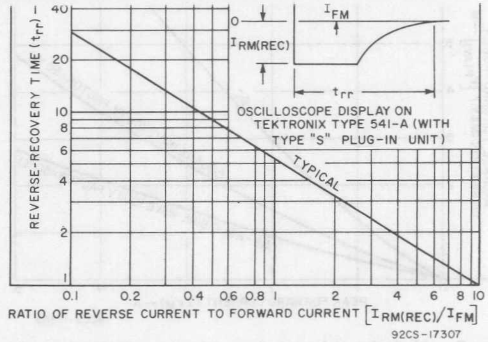
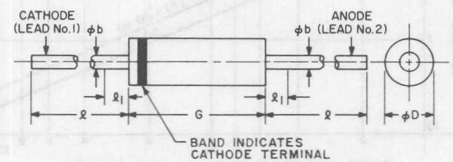


Fig. 8 - Variation of reverse-recovery time with ratio of reverse-to-forward current for types 1N5391--1N5399.

DIMENSIONAL OUTLINE
JEDEC DO-15



92CS-17313

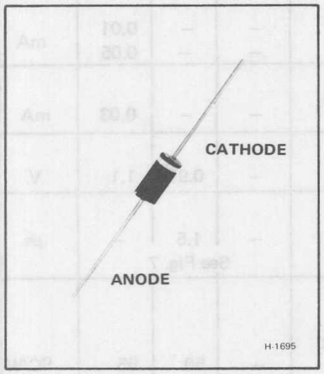
SYMBOL	INCHES		MILLIMETERS	
	MIN.	MAX.	MIN.	MAX.
φb	0.027	0.035	0.686	0.889
φD	0.104	0.140	2.64	3.56
G	0.230	0.300	5.84	7.62
ℓ	1.000	–	25.40	–
ℓ_1*	–	0.050	–	1.27

*Within this zone the diameter may vary to allow for lead finishes and irregularities.

RCA
Solid State
Division

Rectifiers

D1201 Series



1-A, 50-to-1000-V Silicon Rectifiers

Plastic-Packaged, General-Purpose Types for Low-Power Applications

Features:

- **Electrically identical to JEDEC types 1N4001–1N4007**
- **High surge-current capability**
- **Low junction-to-lead thermal impedances**
- **–65 to +175°C operating temperature range**

RCA D1201 series† devices are diffused-junction type silicon rectifiers in an axial-lead plastic package. These devices differ only in their voltage ratings.

Their small size and plastic package of high insulation resistance make these rectifiers especially suited for those applications in which high packing densities are desirable.

† Types D1201A, B, C, D, M, and N were formerly RCA Dev. Nos. TA7996 and TA7802-TA7806, respectively.

MAXIMUM RATINGS, *Absolute-Maximum Values:*

REVERSE VOLTAGE:		D1201F (44001)*	D1201A (44002)*	D1201B (44003)*	D1201D (44004)*	D1201M (44005)*	D1201N (44006)*	D1201P (44007)*	
REPETITIVE PEAK♠	V_{RRM}	50	100	200	400	600	800	1000	V
NON-REPETITIVE PEAK♦	V_{RSM}	100	150	300	525	800	1000	1200	V
WORKING PEAK▲	V_{RWM}	50	100	200	400	600	800	1000	V
DC BLOCKING	V_R	50	100	200	400	600	800	1000	V
RMS	$V_{R(RMS)}$	35	70	140	280	420	560	700	V

		All Types	
FORWARD CURRENT:			
AVERAGE-RECTIFIED:	I_O		A
Single-phase, half-wave operation with 60-Hz sinusoidal voltage and resistive load; with 1" leads. $T_A = 75°C$		1	
For other lead lengths		See Fig. 1	
PEAK-SURGE (NON-REPETITIVE):	I_{FSM}		
For one-half cycle of applied voltage, 50 Hz (10 ms)		28	A
60 Hz (8.3 ms)		30	A
400 Hz (1.25 ms)		60	A
For other durations		See Fig. 3	
TEMPERATURE RANGE:			
With 1-inch leads & infinite-heat-sink mounting (both leads):			
Storage & Operating		–65 to 175	°C
LEAD TEMPERATURE (During Soldering):	T_L		
Measured 3/8 in. (9.52 mm) from case for 10 s max.■		350	°C

* Number in parentheses is a former RCA type number.

♠ For single-phase, half-wave sinusoidal pulse of 100–μs duration and a repetition rate of 60 pulses per second.

♦ For one single-phase, half-wave, 60-Hz sinusoidal pulse with this peak value.

▲ Maximum input voltage that can be continuously applied (with the maximum current rating) over the normal operating-temperature range. For single-phase, half-wave operation with a 60-Hz sinusoidal supply and a resistive load.

■ Measured on anode or cathode lead.

ELECTRICAL CHARACTERISTICS

CHARACTERISTIC	SYMBOL	LIMITS All Types Min.	Typ.	Max.	UNITS
Reverse Current:					
Static					
For V_R = rated value & T_J = 25°C	I_R	–	–	0.01	mA
For V_R = rated value & T_J = 100°C	I_R	–	–	0.05	mA
Dynamic					
Full-cycle average, for V_{RWM} = rated value, I_o = 1 A, T_A = 75°C	$I_{R(AV)}$	–	–	0.03	mA
Instantaneous Forward-Voltage Drop:					
At i_F = 1 A, T_J = 25°C, see Fig. 2	v_F	–	0.95	1.1	V
Reverse-Recovery Time:					
At I_{FSM} = 30 A, pulse duration = 3.1 μs, T_A = 25°C, see Fig. 6	t_{rr}	–	1.5	–	μs
For other conditions	t_{rr}		See Fig. 7		
Thermal Impedance (Junction-to-Heat Sink):					
Steady-State					
Heat-sink mounting with 1-inch leads. For other mounting methods and other lead lengths, see Fig. 4	$\theta_{J\text{-}HS(t)}$	–	50	55	°C/W
Transient					
Heat-sink mounting with 0 to 1" leads, and with a pulse duration of 0.3 s. For other pulse durations, see Fig. 5	$\theta_{J\text{-}HS(t)}$	–	7.5	–	°C/W

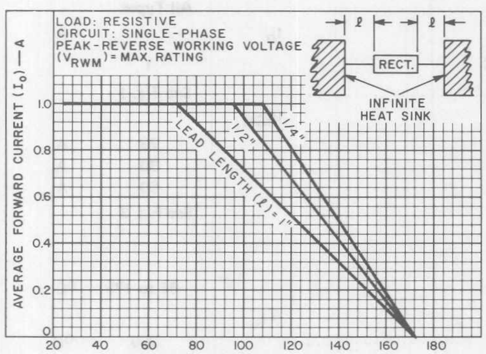


Fig. 1—Average-forward-current derating curves for several lead lengths.

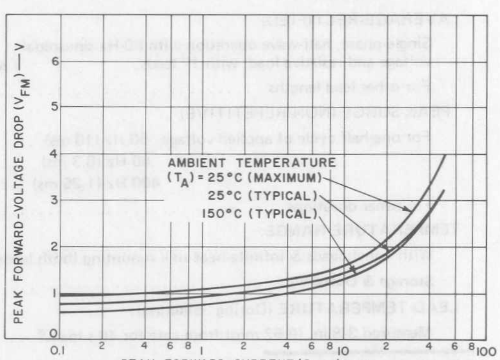


Fig. 2—Peak forward-voltage drop vs. peak forward current.

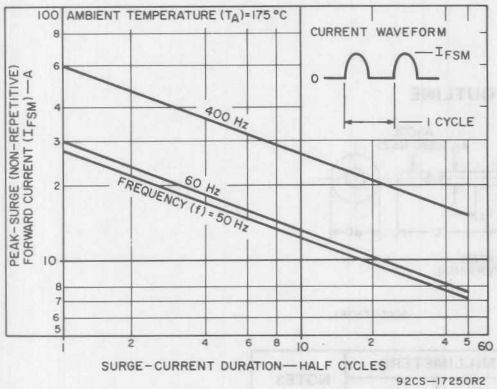


Fig. 3—Peak-surge (non-repetitive) forward current vs. surge-current duration.

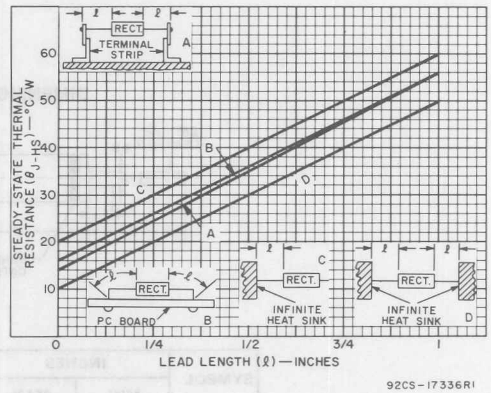


Fig. 4—Typical steady-state thermal resistance with lead length (for different mounting methods).

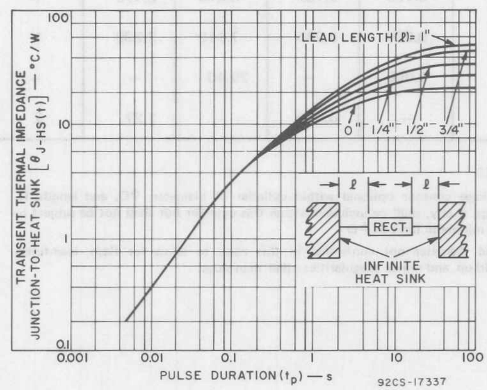


Fig. 5—Typical variation of transient thermal impedance with pulse duration for several lead lengths.

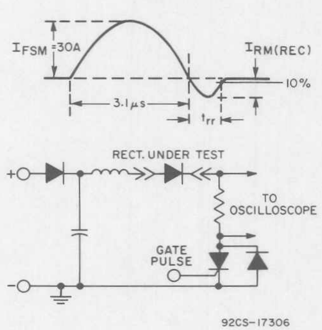


Fig. 6—Oscilloscope display and test circuit for measurement of reverse-recovery time.

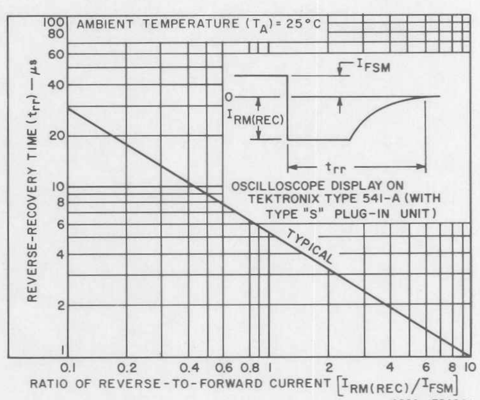
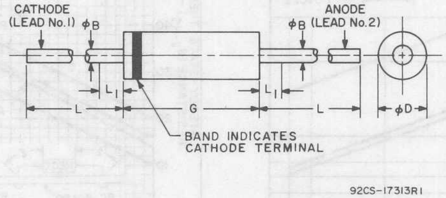


Fig. 7—Typical reverse-recovery time with ratio of reverse-to-forward current.

DIMENSIONAL OUTLINE



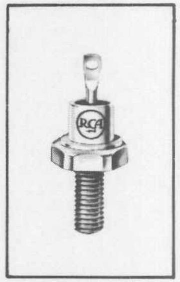
SYMBOL	INCHES		MILLIMETERS		NOTES
	MIN.	MAX.	MIN.	MAX.	
ϕB	0.030	0.034	0.762	0.863	–
ϕD	0.133	0.137	3.378	3.479	1
G	0.280	0.285	7.112	7.239	1
L	1.000	–	25.40	–	–
L_1	–	0.050	–	1.27	2

NOTES

1. Package contour optional within cylinder of diameter, ϕD, and length, G. Slugs, if any, shall be included within this cylinder but shall not be subject to the minimum limit of ϕD.
2. Lead diameter not controlled in this zone to allow for flash, lead-finish build-up, and minor irregularities other than slugs.

These silicon rectifiers are intended for use in generator-type power supplies for mobile equipment; in dc-to-dc converters, power supplies for dc motors, transmitters, rf generators, welding equipment, and electroplating systems; in dc-blocking service, magnetic amplifiers, and in a wide variety of other applications in industrial equipment.

Stud-Mounted Types for Industrial Power Supplies



JEDEC DO-4

HALF-WAVE RECTIFIER SERVICE

Absolute-Maximum Ratings *for Supply Frequency of 60 cps, Single-Phase Operation, and with Resistive or Inductive Load*

	1N1341B	1N1342B	1N1344B	1N1345B	1N1346B	1N1347B	1N1348B
PEAK REVERSE VOLTS	50	100	200	300	400	500	600
TRANSIENT REVERSE VOLTS, NON-REPETITIVE (5-msec max. duration and case temperature range of 0 to 200° C.	100	200	350	450	600	700	800
RMS SUPPLY VOLTS	35	70	140	212	284	355	424
DC BLOCKING VOLTS	50	100	200	300	400	500	600
AVERAGE FORWARD AMPERES: At 150° C case temperature	6	6	6	6	6	6	6
At other case temperatures	See Fig.1						
PEAK RECURRENT AMPERES	25	25	25	25	25	25	25
PEAK SURGE AMPERES:[a] One-half cycle, sine wave	160	160	160	160	160	160	160
CASE-TEMPERATURE RANGE: Operating and Storage	-65 to +200° C						
Characteristics:							
Max. Forward Voltage Drop[b] (Volts)	0.65	0.65	0.65	0.65	0.65	0.65	0.65
Max. Reverse Current (Ma.): Dynamic[b]	0.45	0.45	0.45	0.45	0.45	0.45	0.45
Static[c]	0.004	0.004	0.004	0.004	0.004	0.004	0.004

[a] Superimposed on device operating within the maximum voltage, current, and temperature ratings and may be repeated after sufficient time has elapsed for the device to return to the presurge thermal-equilibrium conditions.

[b] Average value for one complete cycle at case temperature of 150° C and at maximum rated voltage and average forward current.

[c] DC value, at maximum peak reverse voltage, and case temperature (°C) = 25.

- Available in reverse-polarity versions: 1N1341RB, 1N1342RB, 1N1344RB, 1N1345RB, 1N1346RB, 1N1347RB, 1N1348RB
- Designed to meet stringent mechanical and environmental specifications
- Diffused-junction process — exceptional uniformity and stability of characteristics
- Hermetic seals
- Welded construction
- Low thermal resistance
- Low leakage current
- Low forward voltage drop
- JEDEC DO-4 outline
- High output current:
  up to 15 amperes — 6 rectifiers in 3-phase, full-wave bridge circuit
  up to 12 amperes — 4 rectifiers in single-phase full-wave bridge circuit

RATING CHART

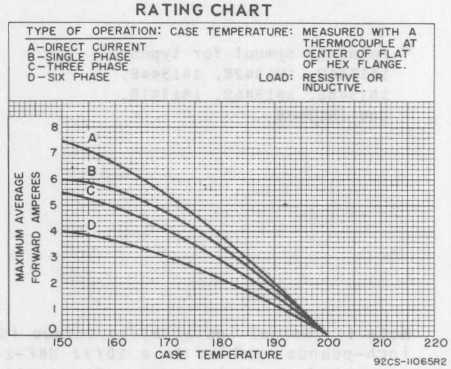
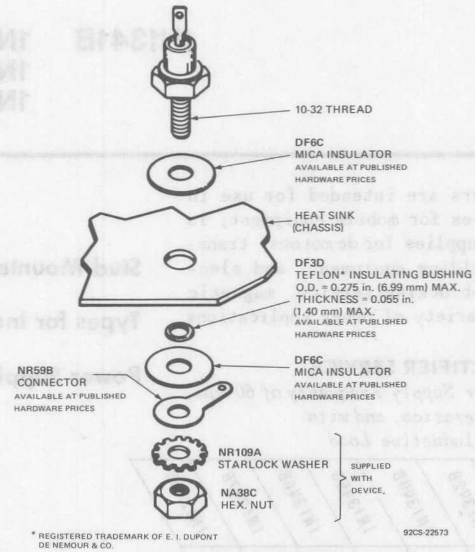


Fig. 1

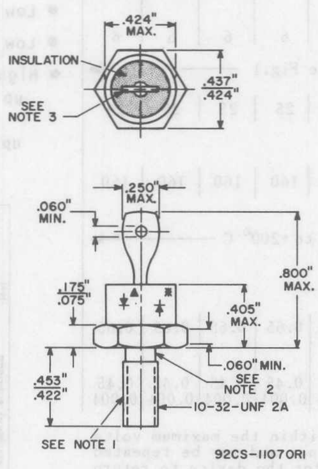


In the United Kingdom, Europe, Middle East, and Africa, mounting-hardware policies may differ; check the availability of all items shown with your RCA sales representative or supplier.

Fig. 2 Suggested Mounting Arrangement.

DIMENSIONAL OUTLINE JEDEC DO-4

▲ Polarity symbol for types 1N1341B, 1N1342B, 1N1344B, 1N1345B, 1N1346B, 1N1347B, and 1N1348B



*Polarity symbol for types 1N1341RB, 1N1342RB, 1N1344RB, 1N1345RB, 1N1346RB, 1N1347RB, and 1N1348RB

Note 1: Normal installation torque is 15 to 20 inch-pounds applied to a 10/32 UNF-2B hex nut assembled on stud thread. The applied torque during installation should not exceed 25 inch-pounds.

Note 2: Diameter of unthreaded portion: 0.189" max., 0.163" min.

Note 3: Angular orientation of this terminal is undefined.

Note 4: The device may be operated in any position.

RCA Solid State Division

Rectifiers

1N1199A 1N1200A 1N1202A 1N1203A 1N1204A 1N1205A 1N1206A

Used in generator-type power supplies for mobile equipment; in dc-to-dc converters, battery chargers, and machine-tool controls; in power supplies for aircraft, marine, and missile equipment, for dc motors, transmitters, rf generators, welding equipment, and electroplating systems; in dc-blocking service, and in a wide variety of other applications in military and industrial equipment.

Stud-Mounted Types for Industrial and Military Power Supplies

JEDEC DO-4

HALF-WAVE RECTIFIER SERVICE

Absolute-Maximum Ratings *for Supply Frequency of 60 cps, Single-Phase Operation, and with Resistive or Inductive Load*

	1N1199-A	1N1200-A	1N1202-A	1N1203-A	1N1204-A	1N1205-A	1N1206-A
PEAK REVERSE VOLTS	50	100	200	300	400	500	600
TRANSIENT REVERSE VOLTS, NON-REPETITIVE (5-msec max. duration and case temperature range of 0 to 200° C)	100	200	350	450	600	700	800
RMS SUPPLY VOLTS	35	70	140	212	284	355	424
DC BLOCKING VOLTS	50	100	200	300	400	500	600
AVERAGE FORWARD AMPERES:							
At 150° C case temperature	12	12	12	12	12	12	12
At other case temperatures	See Fig. 1						
PEAK RECURRENT AMPERES	50	50	50	50	50	50	50
PEAK SURGE AMPERES:●							
One-half cycle, sine wave	240	240	240	240	240	240	240
For one or more than one cycle	See Fig. 4						
CASE-TEMPERATURE RANGE: Operating and Storage	-65 to +200° C						

Characteristics:

	1N1199-A	1N1200-A	1N1202-A	1N1203-A	1N1204-A	1N1205-A	1N1206-A
Max. Forward Voltage Drop▲ (Volts)	0.55	0.55	0.55	0.55	0.55	0.55	0.55
Max. Reverse Current (Ma.):							
Dynamic▲	3	2.5	2	1.75	1.5	1.25	1
Static●	0.004	0.004	0.004	0.004	0.004	0.004	0.004
Max. Thermal Resistance, Junction-to-Case	2°C/Watt						

- available in reverse-polarity versions: 1N1199-RA, 1N1200-RA, 1N1202-RA, 1N1203-RA, 1N1204-RA, 1N1205-RA, 1N1206-RA
- designed to meet stringent military mechanical and environmental specifications
- diffused-junction process — exceptional uniformity and stability of characteristics
- hermetic seals
- welded construction
- low thermal resistance
- low leakage current
- low forward voltage drop
- JEDEC DO-4 outline
- high output current:
  up to 30 amperes — 6 rectifiers in 3-phase, full-wave bridge circuit
  up to 24 amperes — 4 rectifiers in single-phase full-wave bridge circuit

● Superimposed on device operating within the maximum voltage, current, and temperature ratings and may be repeated after sufficient time has elapsed for the device to return to the presurge thermal-equilibrium conditions.

▲ Average value for one complete cycle at case temperature of 150° C and at maximum rated voltage and average forward current.

● DC value, at maximum peak reverse voltage, and case temperature (°C) = 25.

11-73

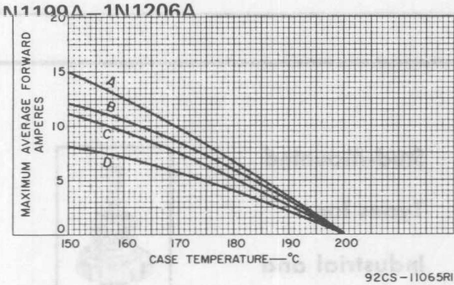


Fig. 1 - Rating Chart for all Types.

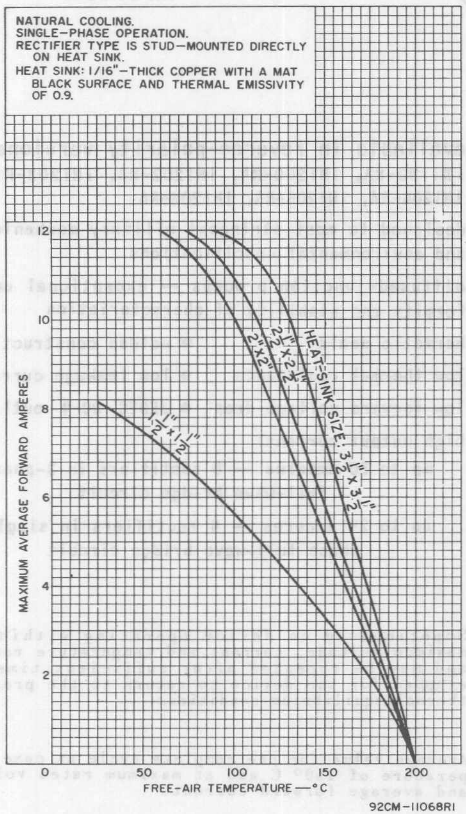


Fig. 2 - Operation Guidance Chart for all Types and corresponding reverse-polarity versions.

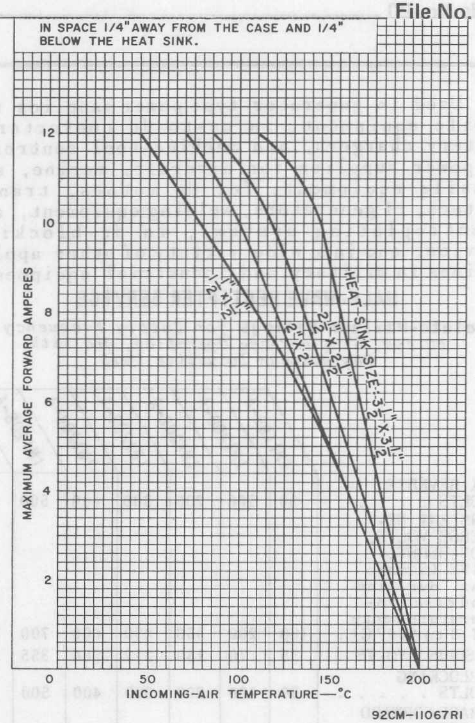


Fig. 3 - Operation Guidance Chart for all Types and corresponding reverse-polarity versions.

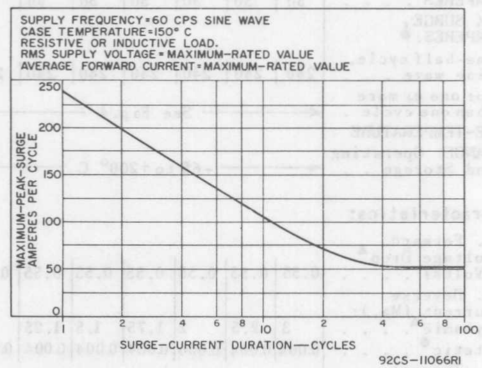


Fig. 4 - Peak-Surge-Current Rating Chart for all Types and corresponding reverse-polarity versions.

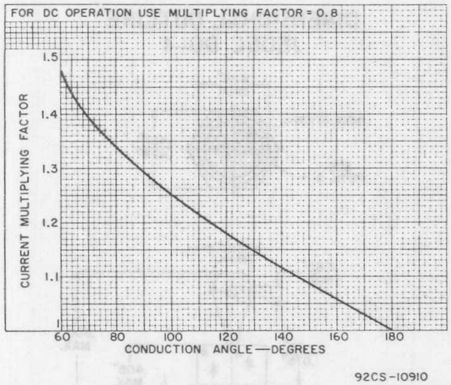


Fig.5 - Current-Multiplying-Factor Chart for Polyphase and DC operation for all Types and corresponding reverse-polarity versions.

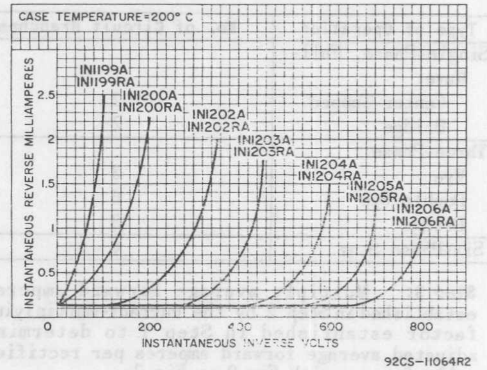


Fig.7 - Typical Reverse Characteristics for all Types and corresponding reverse-polarity versions.

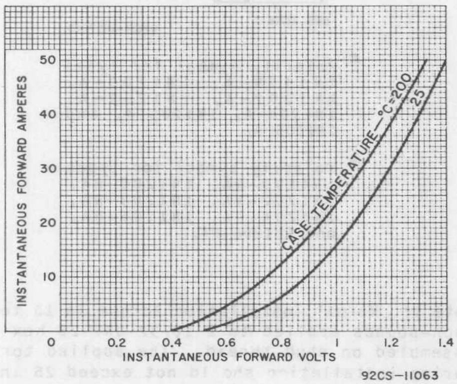
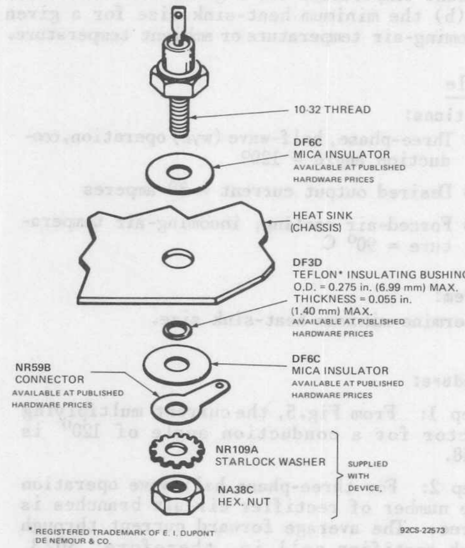


Fig.6 - Typical Forward Characteristics for all Types and corresponding reverse-polarity versions.



In the United Kingdom, Europe, Middle East, and Africa, mounting-hardware policies may differ; check the availability of all items shown with your RCA sales representative or supplier.

Fig.8 - Suggested Mounting Arrangement.

OPERATING CONSIDERATIONS

Because these rectifiers may operate at voltages which are dangerous, care should be taken in the design of equipment to prevent the operator from coming in contact with the rectifier.

The recommended installation torque is 15 to 20 inch-pounds applied to a 10/32 UNF-2B hex nut assembled on stud thread.

The applied torque during installation should not exceed 25 inch-pounds.

Use of Rating Charts and Operation Guidance Chart.

Fig.5 is used in conjunction with Fig.2 and Fig.3 to determine maximum average forward amperes per rectifier cell for polyphase operation and dc operation. The procedure for the use of Fig.5 is as follows:

Step 1: From Fig.5 determine the current-multiplying factor for the applicable conduction angle. (For dc operation use current multiplying factor of 0.8.)

Step 2: Divide the required load current in amperes by the number of rectifier circuit branches — as shown in the following Table — to determine average forward amperes per rectifier cell.

Type of Operation	No. of Circuit Branches
Single-Phase, Full-Wave:	
Center-Tapped	2
Bridge	2
Three-Phase:	
Wye	3
Double Wye	6
Bridge	3
Six-Phase Star	6

Step 3: Multiply average forward amperes established in Step 2 by the current-multiplying factor established in Step 1 to determine adjusted average forward amperes per rectifier cell, for use with Fig.2 or Fig.3.

Step 4: Using the product obtained in Step 3, determine from Fig.2 or Fig.3 either (a) the maximum allowable incoming-air temperature or ambient temperature for a given heat-sink size, or (b) the minimum heat-sink size for a given incoming-air temperature or ambient temperature.

Example

Conditions:

(a) Three-phase, half-wave (wye) operation, conduction angle = 120°

(b) Desired output current = 30 amperes

(c) Forced-air cooling; incoming-air temperature = 90° C

Problem:

Determine minimum heat-sink size.

Procedure:

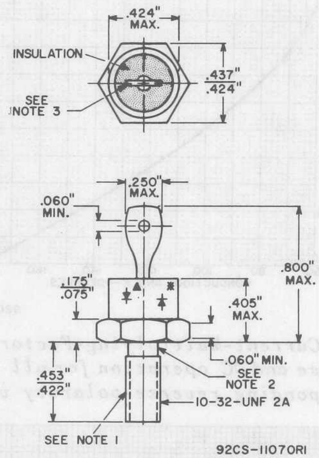
Step 1: From Fig.5, the current multiplying factor for a conduction angle of 120° is 1.18.

Step 2: For three-phase half-wave operation the number of rectifier circuit branches is three. The average forward current through each rectifier cell is, therefore, 30/3, or 10 amperes.

Step 3: Multiplying average forward amperes (10) obtained in Step 2 by the current-multiplying factor (1.18) obtained in Step 1 yields 11.8 adjusted forward amperes.

Step 4: From Fig.3, for forced-air cooling, the minimum heat-sink size for the conditions shown is 2-1/2" x 2-1/2".

DIMENSIONAL OUTLINE JEDEC DO-4



▲ Polarity symbol for types 1N1199-A, 1N1200-A, 1N1202-A, 1N1203-A, 1N1204-A, 1N1205-A, and 1N1206-A.

* Polarity symbol for types 1N1199-RA, 1N1200-RA, 1N1202-RA, 1N1203-RA, 1N1204-RA, 1N1205-RA, and 1N1206-RA.

Note 1: Normal installation torque is 15 to 20 inch-pounds applied to a 10/32 UNF-2B hex nut assembled on stud thread. The applied torque during installation should not exceed 25 inch-pounds.

Note 2: Diameter of unthreaded portion: 0.189" max., 0.163" min.

Note 3: Angular orientation of this terminal is undefined.

Note 4: The device may be operated in any position.

RCA Solid State Division

Rectifiers

1N248C 1N249C 1N250C 1N1195A 1N1196A 1N1197A 1N1198A

Applications:

In power supplies for mobile equipment, dc-to-dc converters, battery chargers, dynamic braking systems, aircraft and missile power supplies, high-power transmitter and rf-generator power supplies, machine-tool controls, dc-motor power supplies, and in other heavy-duty industrial and military equipment.

HALF-WAVE RECTIFIER SERVICE

Maximum Ratings:

Absolute-Maximum Values for Supply Frequency of 60 cps, Single-Phase Operation, and with Resistive or Inductive Load

	1N248-C	1N249-C	1N250-C	1N1195-A	1N1196-A	1N1197-A	1N1198-A
PEAK INVERSE VOLTS	55	110	220	300	400	500	600
RMS SUPPLY VOLTS	39	77	154	212	284	355	424
DC BLOCKING VOLTS	50	100	200	300	400	500	600
FORWARD AMPERES: Average DC: At 150° C case temperature	20	20	20	20	20	20	20
At other temperatures	See Rating Chart I						
PEAK RECURRENT AMPERES	90	90	90	90	90	90	90
PEAK SURGE AMPERES:♦ (One-half cycle, sine wave)	350	350	350	350	350	350	350
(For more than one cycle)	See Rating Chart IV						
CASE TEMPERATURE: Operating and Storage	-65 to +175° C						

Characteristics at 150° C Case Temperature

	1N248-C	1N249-C	1N250-C	1N1195-A	1N1196-A	1N1197-A	1N1198-A
Max. Forward Voltage Drop● (Volts)	0.6	0.6	0.6	0.6	0.6	0.6	0.6
Max. Reverse Current● (Ma.)	3.8	3.6	3.4	3.2	2.5	2.2	1.5

♦ Superimposed on device operating within the maximum specified voltage, current, and temperature ratings and may be repeated after sufficient time has elapsed for the device to return to the presurge thermal equilibrium conditions.

● At maximum peak inverse voltage, average forward amperes = 20, and averaged over one complete cycle.

Stud-Mounted Types for Industrial and Military Power Supplies

JEDEC DO-5

- available in reverse-polarity versions: 1N248-RC, 1N249-RC, 1N250-RC, 1N1195-RA, 1N1196-RA, 1N1197-RA, 1N1198-RA
- designed to meet stringent military mechanical and environmental specifications
- diffused-junction process — exceptional uniformity of characteristics
- hermetic seals
- welded construction
- low thermal resistance
- low leakage current
- low forward voltage drop
- JEDEC DO-5 outline
- high output current: up to
  84 amperes — 6 rectifiers in 3-phase, full-wave bridge circuit
  60 amperes — 4 rectifiers in single-phase full-wave bridge circuit

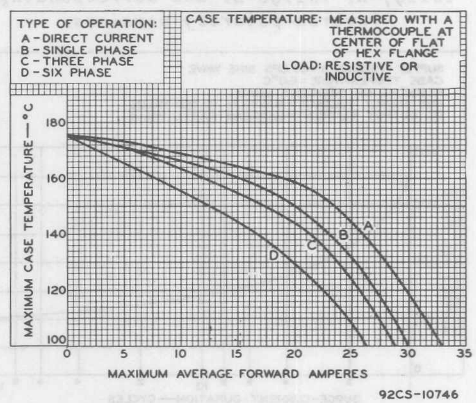


Fig. 1 - Rating Chart 1 for Types 1N248-C, 1N249-C, 1N250-C, 1N1195-A, 1N1196-A, 1N1197-A, 1N1198-A, and corresponding reverse-polarity versions.

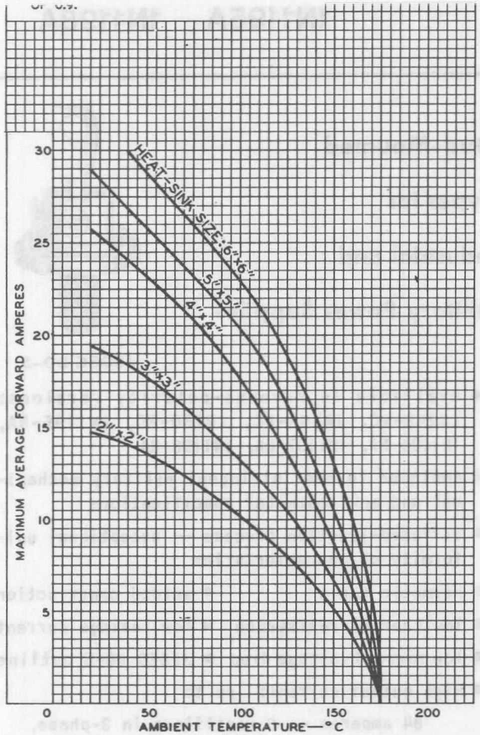


Fig. 2 - Rating Chart II for Types 1N248-C, 1N249-C, 1N250-C, 1N1195-A, 1N1196-A, 1N1197-A, 1N1198-A, and corresponding reverse-polarity versions.

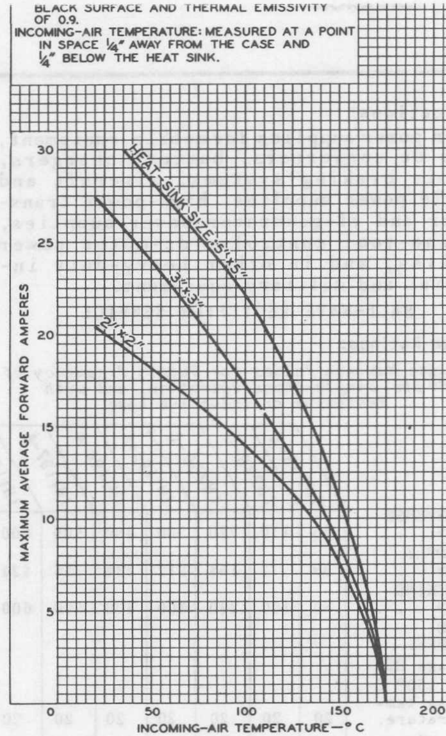


Fig. 3 - Rating Chart III for Types 1N248-C, 1N249-C, 1N250-C, 1N1195-A, 1N1196-A, 1N1197-A, 1N1198-A, and corresponding reverse-polarity versions.

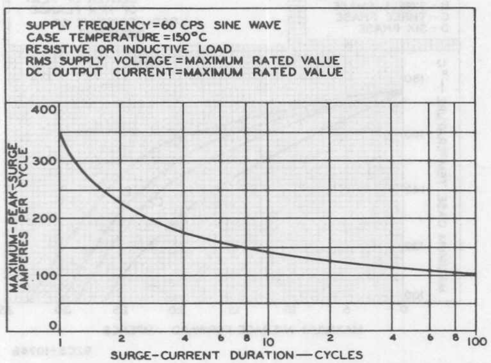


Fig. 4 Rating Chart IV for Types 1N248-C, 1N249-C, 1N250-C, 1N1195-A, 1N1196-A, 1N1197-A, 1N1198-A, and corresponding reverse-polarity versions.

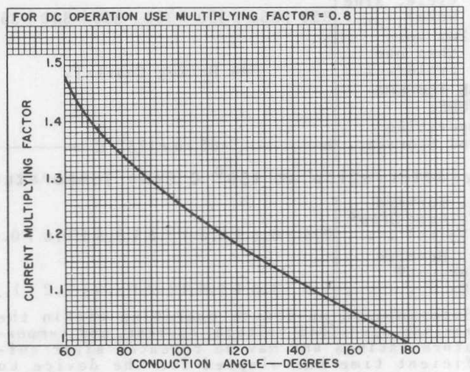


Fig. 5 - Chart V for Types 1N248-C, 1N249-C, 1N250-C, 1N1195-A, 1N1196-A, 1N1197-A, 1N1198-A, and corresponding reverse-polarity versions.

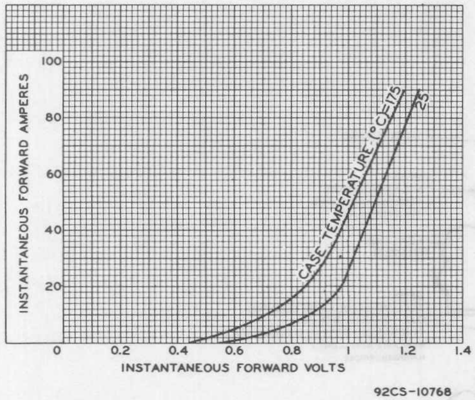


Fig.6 – Typical Forward Characteristics for Types 1N248-C, 1N249-C, 1N250-C, 1N1195-A, 1N1196-A, 1N1197-A, 1N1198-A, and corresponding reverse-polarity versions.

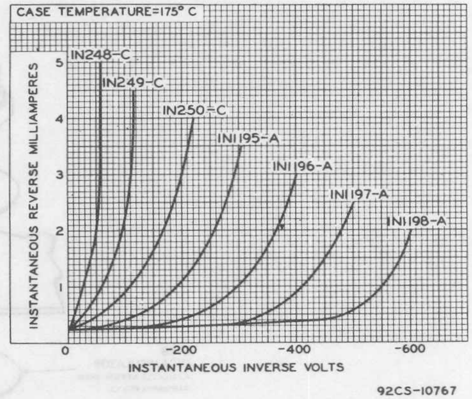


Fig.7 – Typical Reverse Characteristics for Types 1N248-C, 1N249-C, 1N250-C, 1N1195-A, 1N1196-A, 1N1197-A, 1N1198-A, and corresponding reverse-polarity versions.

OPERATING CONSIDERATIONS

Because these rectifiers may operate at voltages which are dangerous, care should be taken in the design of equipment to prevent the operator from coming in contact with the rectifier.

The recommended installation torque is 26 to 36 inch-pounds applied to a 1/4-28 UNF-2A hex nut assembled on thread.

The applied torque during installation should not exceed 75 inch-pounds.

Use of Rating Charts

Chart V is used in conjunction with Rating Charts II and III to determine maximum average forward amperes per rectifier unit for polyphase operation and dc operation. The procedure for the use of Chart V is as follows:

Step 1: From Chart V determine the current-multiplying factor for the applicable conduction angle. (For dc operation use current multiplying factor of 0.8.)

Step 2: Divide the required load current in amperes by the number of rectifier circuit branches — as shown in the following Table — to determine average forward amperes per rectifier element.

Type of Operation	No. of Circuit Branches
Single-Phase, Full-Wave:	
Center-Tapped	2
Bridge	2
Three-Phase:	
Wye	3
Double Wye	6
Bridge	6
Six-Phase Star	6

Step 3: Multiply average forward amperes established in Step 2 by the current multiplying factor established in Step 1 to determine adjusted average forward amperes per rectifier element, for use with Rating Chart II or Rating Chart III.

Step 4: Using the product obtained in Step 3, determine from Rating Chart II or Rating Chart III either (a) the maximum allowable incoming-air temperature or ambient temperature for a given heat-sink size, or (b) the minimum heat-sink size for a given incoming-air temperature or ambient temperature.

Example

Conditions:

(a) Three-phase, half-wave operation; conduction angle = 120°
(b) Desired output current = 45 amperes
(c) Forced-air cooling; incoming-air temperature = 90° C

Problem:

Determine minimum heat-sink size.

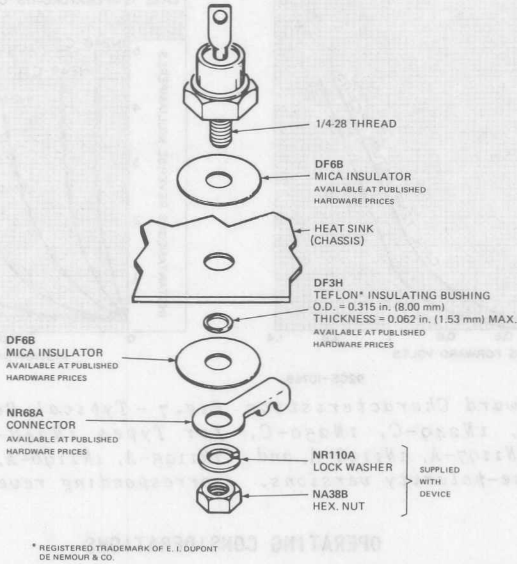
Procedure:

Step 1: From Chart V, the current multiplying factor for a conduction angle of 120° is 1.18.

Step 2: For three-phase half-wave operation the number of rectifier circuit branches is three. The average forward current through each rectifier element is, therefore, 45/3, or 15 amperes.

Step 3: Multiplying average forward amperes (15) obtained in Step 2 by the current multiplying factor (1.18) obtained in Step 1 yields 17.7 adjusted average forward amperes.

Step 4: From Rating Chart III, for forced-air cooling, the minimum heat-sink size for the conditions shown in Step 3 is 3" x 3".

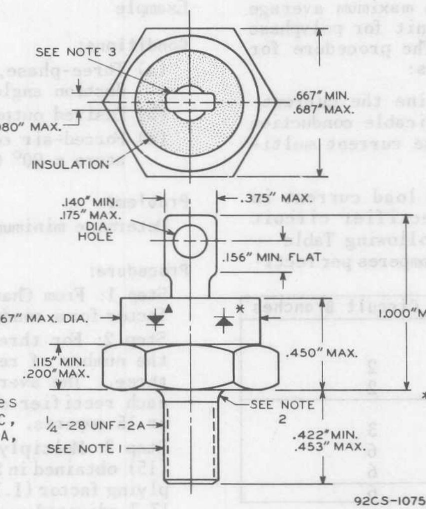


In the United Kingdom, Europe, Middle East, and Africa, mounting-hardware policies may differ; check the availability of all items shown with your RCA sales representative or supplier.

Fig.8 – Suggested Mounting Arrangement.

DIMENSIONAL OUTLINE

JEDEC DO-5



▲ Polarity symbol for types 1N248-C, 1N249-C, 1N250-C, 1N1195-A, 1N1196-A, 1N1197-A, and 1N1198-A.

* Polarity symbol for types 1N248-RC, 1N249-RC, 1N250-RC, 1N1195-RA, 1N1196-RA, 1N1197-RA, and 1N1198-RA.

NOTE 1: MUST WITHSTAND TORQUE OF 30 INCH-POUNDS APPLIED TO 1/4-28 UNF-2A NUT ASSEMBLED ON THREAD.

NOTE 2: ANGULAR ORIENTATION OF THIS TERMINAL UNDEFINED.

NOTE 3: DEVICE CAN BE USED IN ANY POSITION.

RCA
Solid State
Division

Rectifiers
1N1183A 1N1184A 1N1186A-1N1190A

H-1113R2

JEDEC DO-5

40-Ampere Silicon Rectifiers

Stud-Mounted Types for Industrial and Military Power Supplies

Features:

- **Low thermal resistance**
- **Low forward voltage drop**
- **High output current:**
  up to 160 amperes – 6 rectifiers in 3-phase, full-wave bridge circuit
  up to 120 amperes – 4 rectifiers in single-phase, full-wave bridge circuit
- **Welded construction**
- **Low leakage current**
- **JEDEC DO-5 Outline**
- **Available in reverse-polarity versions:**
  1N1183RA, 1N1184RA, 1N1186RA, 1N1187RA, 1N1188RA, 1N1189RA, 1N1190RA
- **Extra-high-strength zirconium-alloy mounting stud – withstands installation torque of up to 50 inch-pounds**
- **Designed to meet stringent military mechanical and environmental specifications.**

RCA-1N1183A, 1N1184A, 1N1186A, 1N1187A, 1N1188A, 1N1189A, and 1N1190A are 40-ampere, diffused-junction silicon rectifiers suitable for use in generator-type power supplies for mobile electrical and electronic equipment, in dc-to-dc converters and battery chargers, and in power supplies for aircraft, marine, and missile equipment, transmitters, and rf generators. They are also extremely useful in power supplies for dc motors, in welding and electroplating equipment, in dc-blocking applications, in magnetic amplifiers, and in a wide variety of other applications in heavy-duty industrial and military equipment.

- **Diffused-junction process – exceptional uniformity and stability of characteristics**
- **Hermetic seals**

These rectifiers are conservatively rated to permit continuous operation at maximum ratings in applications requiring high reliability under severe operating conditions. In addition, they utilize a special zirconium-alloy mounting stud which can withstand installation torques of up to 50 inch-pounds – a feature of significant value in applications involving mechanical shock and vibration.

HALF-WAVE RECTIFIER SERVICE, ABSOLUTE-MAXIMUM RATINGS, *for Supply Frequency of 60 cps, Single-phase Operation, and with Resistive or Inductive Load*

	1N1183A	1N1184A	1N1186A	1N1187A	1N1188A	1N1189A	1N1190A
PEAK REVERSE VOLTS	50	100	200	300	400	500	600
RMS SUPPLY VOLTS	35	70	140	212	284	355	424
DC BLOCKING VOLTS	50	100	200	300	400	500	600
AVERAGE FORWARD AMPERES:							
At 150°C case temperature	40 (all types)						
At other case temperatures	See Fig. 1 (all types)						
PEAK SURGE AMPERES:[a]							
One-half cycle, sine wave	800 (all types)						
For more than one cycle	See Fig. 5 (all types)						
PEAK RECURRENT AMPERES	195 (all types)						
CASE TEMPERATURE RANGE:							
Operating and storage	-65 to +200°C (all types)						
Characteristics:							
Max. Forward Voltage Drop (Volts)[b]	0.65 (all types)						
Max. Reverse Current (mA):							
Dynamic[b]	2.5	2.5	2.5	2.5	2.2	2	1.8
Static[c]	0.015 (all types)						
Max. Thermal Resistance, Junction-to-Case	1° C/W (all types)						

[a] Superimposed on device operating within the maximum specified voltage, current, and temperature ratings and may be repeated after sufficient time has elapsed for the device to return to the presurge thermal-equilibrium conditions.

[b] Average value for one complete cycle, at maximum peak reverse voltage, maximum average forward amperes = 40, and case temperature (°C) = 150.

[c] DC value, at maximum peak reverse voltage and case temperature (°C) = 25.

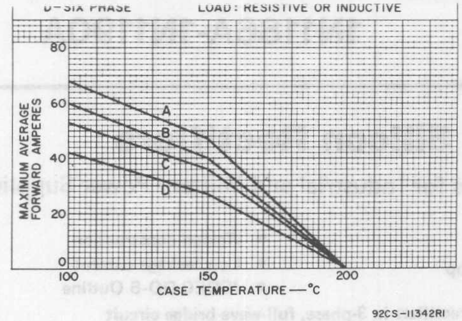


Fig.1— Rating chart for all types and corresponding reverse-polarity versions.

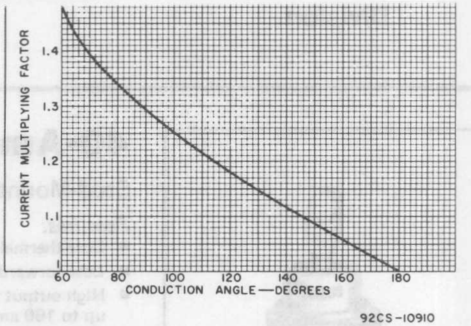


Fig.2— Current-multiplying-factor chart for polyphase and dc operation for all types and corresponding reverse-polarity versions.

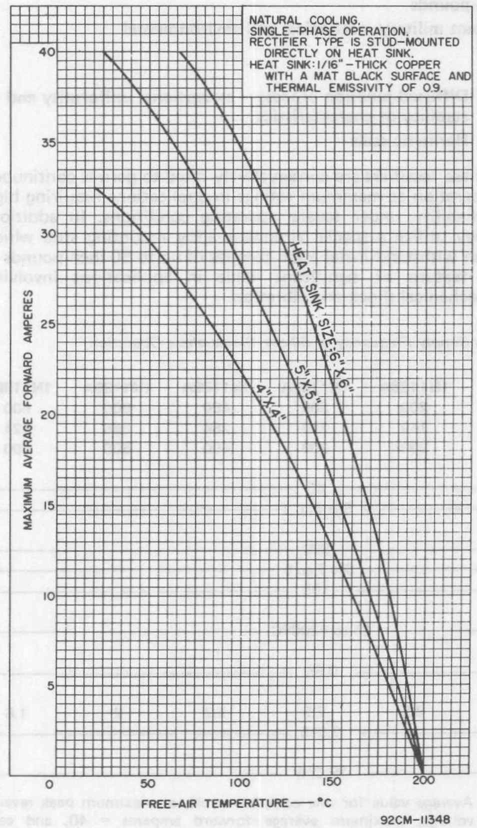


Fig.3— Operation guidance chart for all types and corresponding reverse-polarity versions.

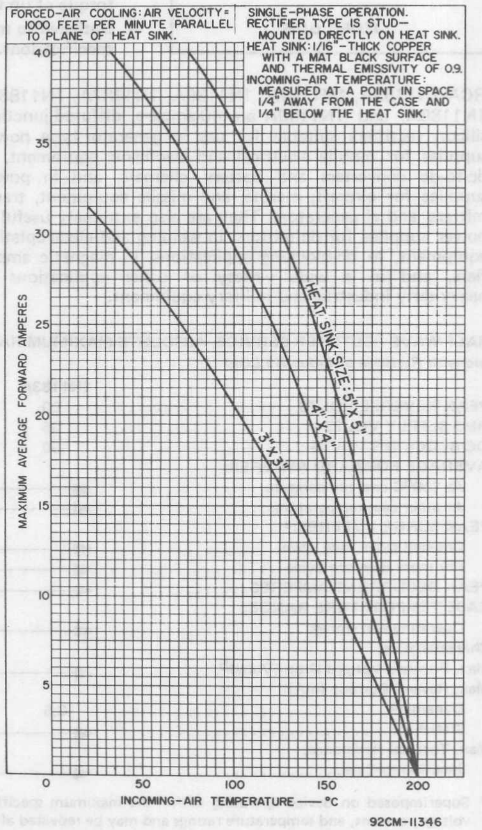


Fig.4— Operation guidance chart for all types and corresponding reverse-polarity versions.

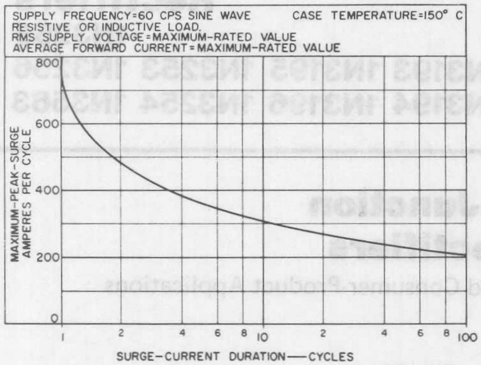


Fig.5– Surge-current rating chart for all types and corresponding reverse-polarity versions.

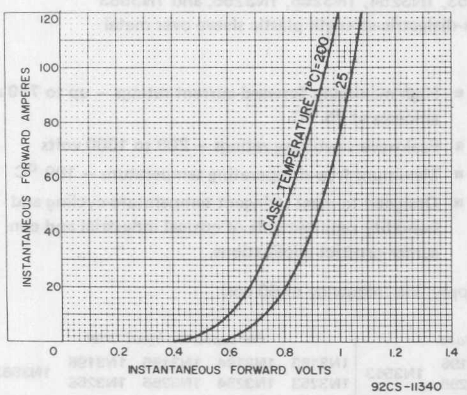


Fig.6– Typical forward characteristics for all types and corresponding reverse-polarity versions.

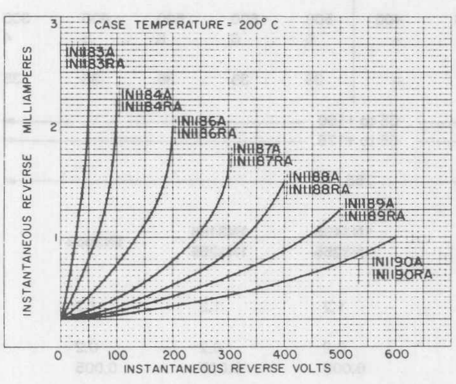
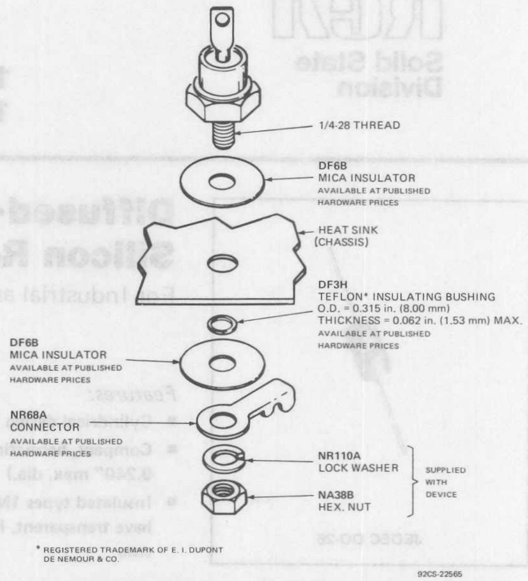


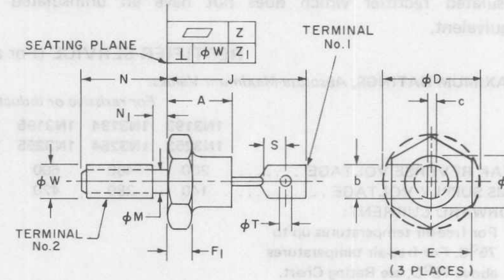
Fig.7– Typical reverse characteristics for all types and corresponding reverse-polarity versions.



In the United Kingdom, Europe, Middle East, and Africa, mounting-hardware policies may differ; check the availability of all items shown with your RCA sales representative or supplier.

Fig.8 – Suggested mounting arrangement.

DIMENSIONAL OUTLINE (JEDEC DO-5)



SYMBOL	INCHES MIN.	INCHES MAX.	MILLIMETERS MIN.	MILLIMETERS MAX.	NOTES
A	–	0.450	–	11.43	
b	–	0.375	–	9.52	2
c	0.030	0.080	0.77	2.03	
ϕD	–	0.794	–	20.16	
$ϕD_1$	–	0.667	–	16.94	
E	0.669	0.688	17.00	17.47	
F_1	0.115	0.200	2.93	5.08	1
J	0.750	1.000	19.05	25.40	
ϕM	0.220	0.249	5.59	6.32	
N	0.422	0.453	10.72	11.50	
N_1	–	0.090	–	2.28	
S	0.156	–	3.97	–	
ϕT	0.140	0.175	3.56	4.44	
ϕW	1/4-28 UNF 2A		1/4-28 UNF 2A		3
Z	–	0.002	–	0.050	
Z_1	–	0.006	–	0.152	

NOTES:

1: Chamfer or undercut on one or both sides of hexagonal base is optional.

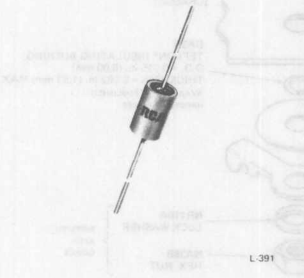
2: Angular orientation and contour of Terminal No. 1 is optional.

3: ϕW is pitch diameter of coated threads. REF: Screw-Thread Standards for Federal Services, Handbook H 28 Part I. Recommended torque: 30 inch-pounds.

92CS-20473

RCA
Solid State
Division

Rectifiers
1N3255
1N3193 1N3195 1N3253 1N3256
1N3194 1N3196 1N3254 1N3563



JEDEC DO-26

Diffused-Junction Silicon Rectifiers

For Industrial and Consumer-Product Applications

Features:

- **Cylindrical design with axial leads for simple handling and installation**
- **Compact, hermetically sealed metal case (0.405" max. length; 0.240" max. dia.)**
- **Insulated types 1N3253, 1N3254, 1N3255, 1N3256, and 1N3563 have transparent, high-dielectric-strength plastic sleeve over metal case**
- **High maximum forward-current ratings – up to 750 milliamperes at 75 °C**
- **Peak-reverse-voltage ratings – 200 to 1000 volts**
- **Maximum free-air operating temperature – 100 °C**
- **Designed to meet stringent temperature-cycling and humidity requirements of critical industrial and consumer-product applications**

RCA-1N3193, 1N3194, 1N3195, 1N3196, 1N3253, 1N3254, 1N3255, 1N3256, and 1N3563 are hermetically sealed silicon rectifiers of the diffused-junction type utilizing small cylindrical metal cases and axial leads. Types 1N3253, 1N3254, 1N3255, and 1N3256 are insulated versions of types 1N3193, 1N3194, and 1N3196, respectively. Type 1N3563 is an insulated rectifier which does not have an uninsulated equivalent.

RECTIFIER SERVICE (For a supply-line frequency of 60 cps)

MAXIMUM RATINGS, *Absolute-Maximum Values:*

	For resistive or inductive load					*For capacitor-input filter*					
	1N3193 1N3253	1N3194 1N3254	1N3195 1N3255	1N3196 1N3256	1N3563	1N3193 1N3253	1N3194 1N3254	1N3195 1N3255	1N3196 1N3256	1N3563	
PEAK REVERSE VOLTAGE	200	400	600	800	1000	200	400	600	800	1000	volts
RMS SUPPLY VOLTAGE	140	280	420	560	700	70	140	210	280	350	volts
FORWARD CURRENT:											
For free-air temperatures up to 75°C. For free-air temperatures above 75°C, see Rating Chart.											
DC	750	750	750	500	400	500	500	500	400	300	ma
PEAK RECURRENT	–	–	–	–	–	6	6	6	5	4	amp
SURGE – For "turn-on" time of 2 milliseconds	–	–	–	–	–	35	35	35	35	35	amp
FREE-AIR-TEMPERATURE RANGE:											
Operating	-65 to +100										°C
Storage	-65 to +175										°C
LEAD TEMPERATURE:											
For 10 seconds maximum	255										°C

Characteristics, *At a Free-Air Temperature of 25°C:*

	1N3193 1N3253	1N3194 1N3254	1N3195 1N3255	1N3196 1N3256	1N3563	
Maximum Instantaneous Forward Voltage Drop at dc forward current of 0.5 ampere	1.2	1.2	1.2	1.2	1.2	volts
Maximum Reverse Current:						
Dynamic, at T_{FA} = 75°C*	0.2	0.2	0.2	0.2	0.2	ma
Static, at T_{FA} = 25°C**	0.005	0.005	0.005	0.005	0.005	ma

*At max. peak reverse voltage and max. dc forward current.

**At max. peak reverse voltage and zero forward current.

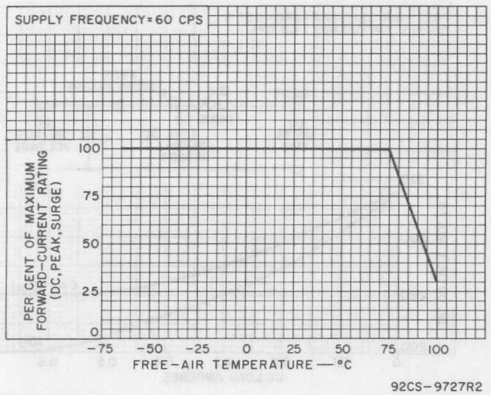


Fig.1– Rating chart for types 1N3193 to 1N3196, 1N3253 to 1N3256, and 1N3563.

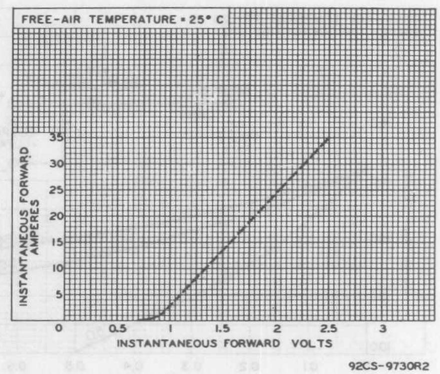


Fig.2– Typical forward characteristics for types 1N3193 to 1N3196, 1N3253 to 1N3256, and 1N3563.

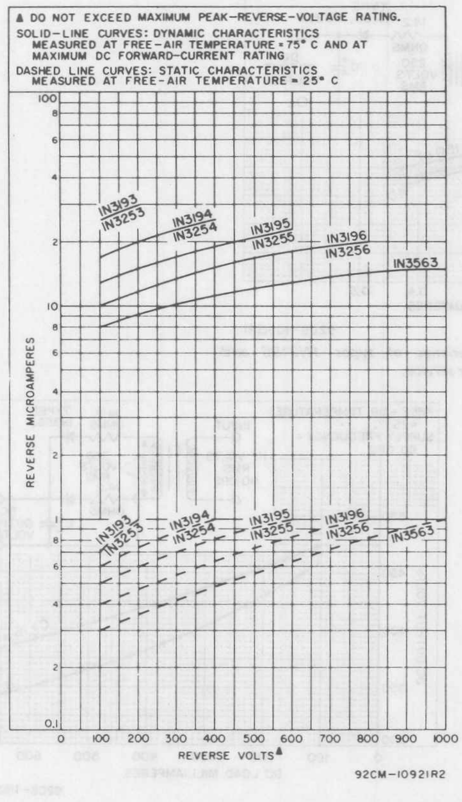


Fig.3– Typical reverse characteristics for types 1N3193 to 1N3196, 1N3253 to 1N3256, and 1N3563.

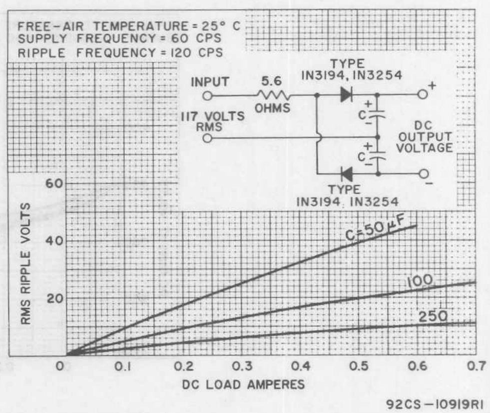


Fig.4– Typical operation characteristics of types 1N3194 and 1N3254 in full-wave voltage-doubler service.

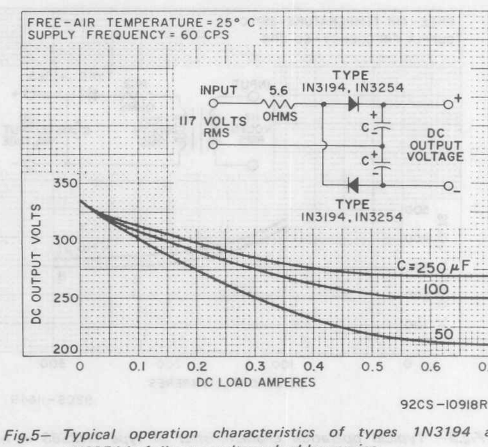


Fig.5– Typical operation characteristics of types 1N3194 and 1N3254 in full-wave voltage-doubler service.

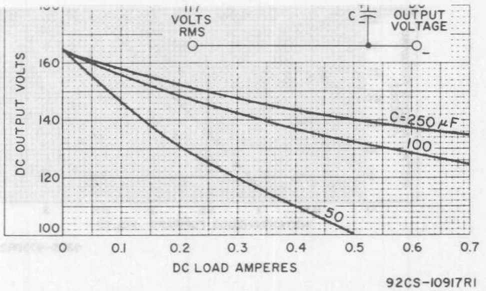


Fig.6– Typical operation characteristics of types 1N3194 and 1N3254 in half-wave rectifier service.

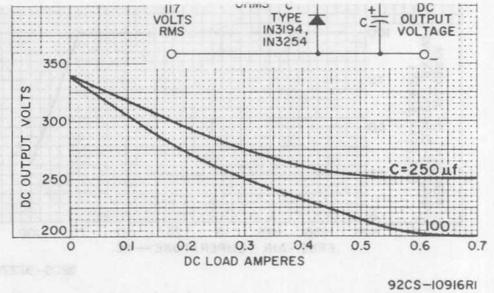


Fig.7– Typical operation characteristics of types 1N3194 and 1N3254 in half-wave voltage-doubler service.

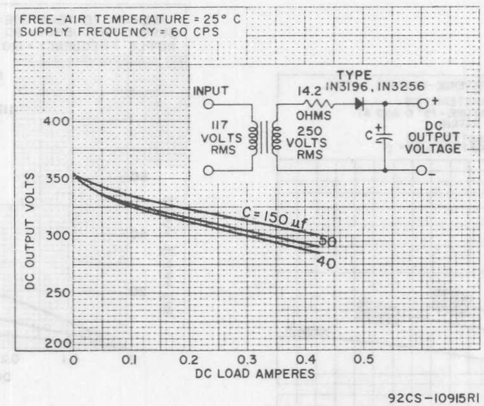


Fig.8– Typical operation characteristics of types 1N3196 and 1N3256 in half-wave rectifier service.

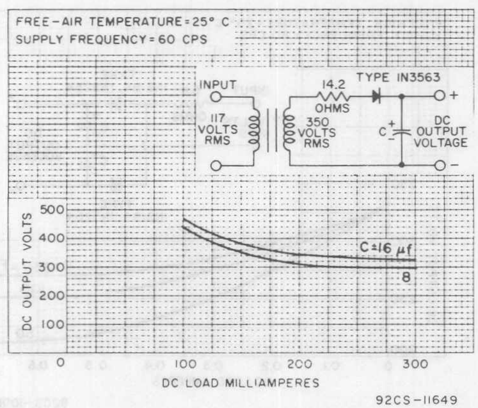


Fig.9– Typical operation characteristics of type 1N3563 in half-wave rectifier service.

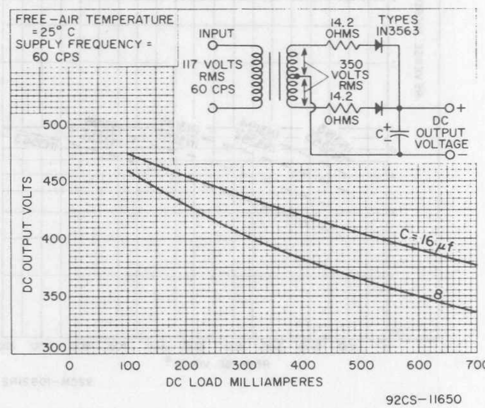
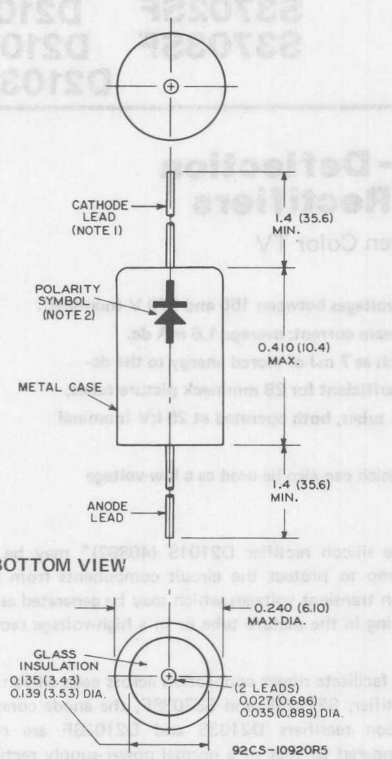


Fig.10–Typical operation characteristics of type 1N3563 in full-wave rectifier service.

DIMENSIONAL OUTLINE (JEDEC DO-26) for 1N3193, 1N3194, 1N3195, and 1N3196

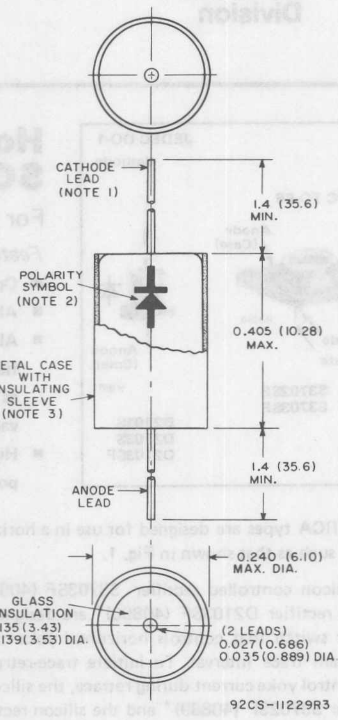


NOTE 1: CONNECTED TO METAL CASE.

NOTE 2: ARROW INDICATED DIRECTION OF FORWARD (EASY) CURRENT FLOW AS INDICATED BY DC AMMETER.

Dimensions in inches and millimeters (values in parentheses).

DIMENSIONAL OUTLINE (JEDEC-DO-26 with insulating sleeve) for 1N3253, 1N3254, 1N3255, 1N3256, and 1N3563



NOTE 1: CONNECTED TO METAL CASE.

NOTE 2: ARROW INDICATES DIRECTION OF FORWARD (EASY) CURRENT FLOW AS INDICATED BY DC AMMETER.

NOTE 3: INSULATOR SLEEVE MAY EXTEND 1/16" BEYOND ENDS OF CASE.

Dimensions in inches and millimeters (values in parentheses).

Specifications of Insulating Sleeve

Material: Plastic

Wall Thickness: 0.002"

Dielectric Strength: 4500 volts/mil at 25°C
3150 volts/mil at 150°C

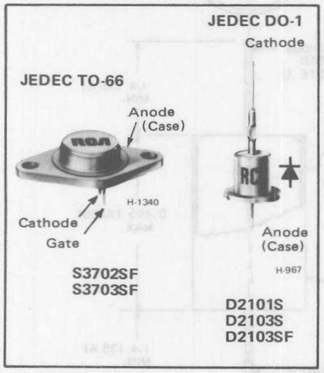
Moisture Absorption: 0.3%
Surface resistivity is not affected by moisture.

Degree of Transparency: Optically clear

RCA Solid State Division

Thyristors/Rectifiers

S3702SF S3703SF D2101S D2103S D2103SF



Horizontial-Deflection SCR's and Rectifiers

For 110° Large-Screen Color TV

Features:

- **Operation from supply voltages between 150 and 270 V (nominal).**
- **Ability to handle high beam current; average 1.6 mA dc.**
- **Ability to supply as much as 7 mJ of stored energy to the deflection yoke, which is sufficient for 29 mm-neck picture tubes, as well as 36.5 mm-neck tubes, both operated at 25 kV (nominal value).**
- **Highly reliable circuit which can also be used as a low-voltage power supply.**

These RCA types are designed for use in a horizontal output circuit such as that shown in Fig. 1.

The silicon controlled rectifier S3703SF (40888)* and the silicon rectifier D2103SF (40890)* are designed to act as a bipolar switch that controls horizontal yoke current during the beam trace interval. To initiate trace-retrace switching and control yoke current during retrace, the silicon controlled rectifier S3702SF (40889)* and the silicon rectifier D2103S (40891)* act as the commutating switch.

***Numbers in parentheses (e.g. 40888) are former RCA type numbers.**

The silicon rectifier D2101S (40892)* may be used as a clamp to protect the circuit components from excessively high transient voltages which may be generated as a result of arcing in the picture tube or in a high-voltage rectifier tube.

To facilitate direct connection across each silicon controlled rectifier, S3702SF and S3703SF, the anode connections of silicon rectifiers D2103S and D2103SF are reversed as compared to that of a normal power-supply rectifier diode.

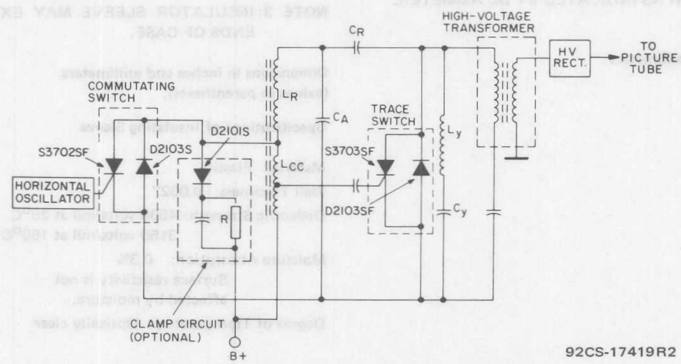


Fig. 1 – Simplified schematic diagram of horizontal output circuit.

For a description of the operation of SCR deflection systems see RCA Application Note AN-3780, "A New Horizontal Deflection System Using S3705M and S3706M Silicon Controlled Rectifiers"; ST-3871; "An SCR Horizontal-Sawtooth-Current and High-Voltage Generator for Magnetically Deflected Picture Tubes"; ST-3835, "Switching-Device Requirements for a New Horizontal-Deflection System".

MAXIMUM RATINGS, *Absolute-Maximum Values:*

SILICON CONTROLLED RECTIFIERS

		TRACE SCR S3703SF	COMMUTATING SCR S3702SF	
Non-Repetitive Peak Off-State Voltage:				
Gate open	V_{DSOM}	800*	750*	V
Repetitive Peak Off-State Voltage:				
Gate open	V_{DROM}			
$T_C = 80^oC$		750	700	V
Repetitive Peak Reverse Voltage:				
Gate open	V_{RROM}	25	25	V
On-State Current:				
$T_C = 60^oC$, 50 Hz sine wave, conduction angle = 180°:				
Average DC	$I_{T(AV)}$	3.2	3.2	A
RMS	$I_{T(RMS)}$	5	5	A
Peak Surge (Non-Repetitive):				
For one cycle of applied voltage, 50 Hz	I_{TSM}	50	50	A
Critical Rate of Rise of On-State Current:				
For $V_D = V_{DROM}$ rated value, I_{GT} = 50 mA, 0.1 μs rise time	di/dt	200	200	A/μs
Gate Power Dissipation●:				
Peak (forward or reverse) for 10 μs duration, max. reverse gate bias = −35 V	P_{GM}	25	25	W
Temperature Range■:				
Storage	T_{stg}		−40 to 150	°C
Operating (case)	T_C		−40 to 80	°C

*Protection against transients above this value must be provided. Transients generated by arcing may persist for as long as 10 cycles.

●Any product of gate current and gate voltage which results in a gate power less than the maximum is permitted.

■Temperature measurement point is shown on the DIMENSIONAL OUTLINE.

ELECTRICAL CHARACTERISTICS, *At Maximum Ratings and at Indicated Case Temperature (T_C)*

SILICON CONTROLLED RECTIFIERS

CHARACTERISTIC	SYMBOL	LIMITS S3703SF TYP.	S3703SF MAX.	S3702SF TYP.	S3702SF MAX.	UNITS
Peak Forward Off-State Current: Gate open, V_{DO} = Rated V_{DROM}, $T_C = 85^oC$	I_{DOM}	0.5	1.5	0.5	1.5	mA
Instantaneous On-State Voltage: i_T = 20 A, $T_C = 25^oC$	v_T	2.2	3	2.2	3	V
DC Gate Trigger Current: $T_C = 25^oC$	I_{GT}	15	40	15	45	mA
DC Gate Trigger Voltage: $T_C = 25^oC$	V_{GT}	1.8	4	1.8	4	V
Critical Rate-of Rise of Off-State Voltage: $T_C = 70^oC$	dv/dt	700 (MIN.)▲		700 (MIN.)▲		V/μs
Circuit-Commutated Turn-Off Time†: $T_C = 70^oC$, Minimum negative bias during turn-off time = −20 V (S3703SF) and −2.5 V (S3702SF)						
Rate of Reapplied Voltage (dv/dt) = 175 V/μs	t_q	–	2.4	–	–	μs
Rate of Reapplied Voltage (dv/dt) = 400 V/μs		–	–	–	4.2	μs
Thermal Resistance: Junction-to-Case	$R_{\theta JC}$	–	4	–	4	°C/W

▲ Up to 500 V max. See Fig. 3.

† This parameter, the sum of reverse recovery time and gate recovery time, is measured from the zero crossing of current to the start of the reapplied voltage. Knowledge of the current, the reapplied voltage, and the case temperature is necessary when measuring t_q. In the worst conditions (high line, zero-beam, off-frequency, minimum auxiliary load, etc.), turn-off time must not fall below the given values. Turn-off time increases with temperature; therefore, case temperature must not exceed 70°C. See Figs. 2 & 3.

	Symbol	TRACE D2103SF	COMMUTATING D2103S	CLAMP D2101S	
REVERSE VOLTAGE**:					
Non-repetitive peak●●	V_{RSM}	750	700	700	V
Repetitive peak	V_{RRM}	800	800	800	V
FORWARD CURRENT:					
RMS	$I_{F(RMS)}$	3■■	3■■	1**	A
Peak-surge (non-repetitive)●●	I_{FSM}	70	70	30	A
Peak (repetitive)	I_{FRM}	7	12	0.5	A
TEMPERATURE RANGE:					
Storage	T_{stg}		–30 to 150		^{o}C
Operating (Case)	T_C		–30 to 80		^{o}C
LEAD TEMPERATURE▲▲:					
For 10-s maximum	T_L		225		^{o}C

** For ambient temperatures up to 45°C.
●● For a maximum of 3 pulses, 10 μs in duration, during any 64 μs period.
■■ Maximum current rating applies only if the rectifier is properly mounted to maintain junction temperature below 150°C. See Fig. 4.
▲▲ At distances no closer to rectifier body than points A and B on outline drawing.

ELECTRICAL CHARACTERISTICS
SILICON RECTIFIERS

CHARACTERISTIC	SYMBOL	MAXIMUM LIMITS D2103S D2103SF	MAXIMUM LIMITS D2101S	UNITS
Reverse Current: Static				
For V_{RRM} = max. rated value, I_F = 0, T_C = 25°C	I_{RM}	10	–	μA
For V_R = 500 V, T_C = 100 °C		250	–	
Instantaneous Forward Voltage Drop: At I_F = 4 A, T_A = 75°C	v_F	1.4	1.5	V
Reverse-Recovery Time: I_{FM} = 3.14 A, ½ sinewave, –di/dt = – 10 A/μs, pulse duration = 0.94 μs, T_C = 25°C	t_{rr}	0.5	0.7	μs

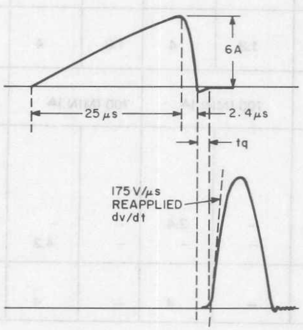


Fig. 2 – Circuit-commutated turn-off in the trace SCR S3703SF.

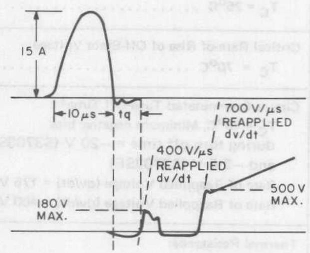
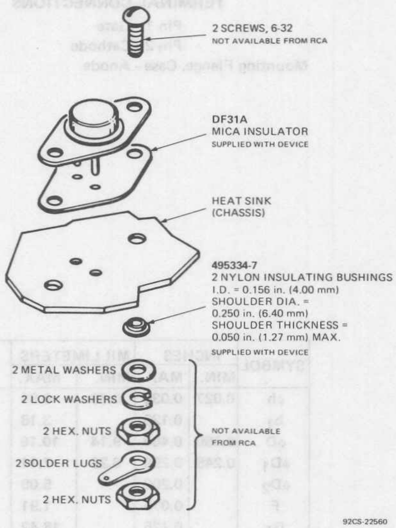


Fig. 3 – Circuit-commutated turn-off time in the commutating SCR S3702SF.

MOUNTING SCR's AND RECTIFIERS

The SCR's and rectifiers can be operated at full current only if they have adequate heat sinking. The procedure illustrated in Fig. 4 should be used when mounting the SCR's. A single aluminum plate made as shown in Fig. 5 will provide adequate heat sinking for trace and commutating rectifiers. Lip punching of the chassis at one end of the clamp plate, makes it possible to mount the rectifier using only one screw.

S3702SF and S3703SF fit socket PTS-4 (United International Dynamics Corp., 2029 Taft St., Hollywood, Fla.), or equivalent.



In the United Kingdom, Europe, Middle East, and Africa, mounting-hardware policies may differ; check the availability of all items shown with your RCA sales representative or supplier.

Fig.4—Suggested hardware and mounting arrangement for SCR's S3702SF and S3703SF.

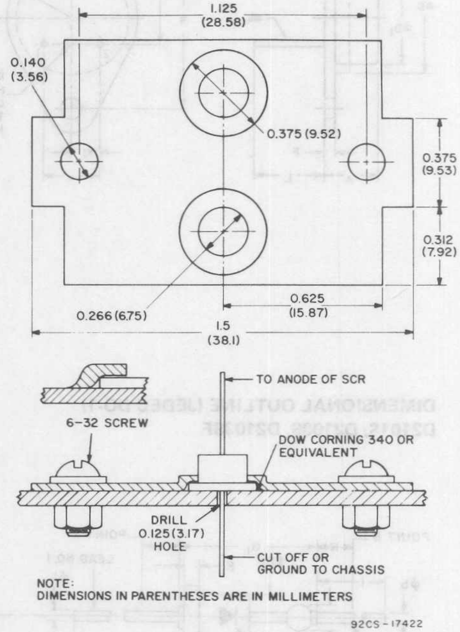
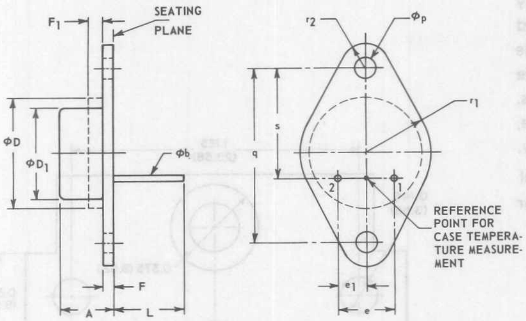


Fig.5—Suggested clamp plate and mounting arrangement for rectifiers D2103S and D2103SF.

DIMENSIONAL OUTLINE (JEDEC TO-66)
S3702SF, S3703SF



SYMBOL	INCHES MIN.	INCHES MAX.	MILLIMETERS MIN.	MILLIMETERS MAX.	NOTES
A	0.250	0.340	6.35	8.64	
φb	0.028	0.034	0.711	0.863	
φD	—	0.620	—	15.75	
φD_1	0.470	0.500	11.94	12.70	
e	0.190	0.210	4.83	5.33	
e_1	0.093	0.107	2.36	2.72	
F	0.050	0.075	1.27	1.91	2
F_1	—	0.050	—	1.27	1
L	0.360	—	9.14	—	
φp	0.142	0.152	3.61	3.86	
q	0.958	0.962	24.33	24.43	
r_1	—	0.350	—	8.89	
r_2	—	0.145	—	3.68	
s	0.570	0.590	14.48	14.99	

NOTES:

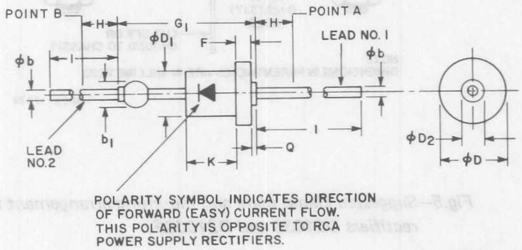
1. The outline contour is optional within zone defined by φD and F_1.
2. Dimensions does not include seating flanges.

92SS-3738

TERMINAL CONNECTIONS

Pin 1 - Gate
Pin 2 - Cathode
Mounting Flange, Case - Anode

DIMENSIONAL OUTLINE (JEDEC DO-1)
D2101S, D2103S, D2103SF



92CS-17423

SYMBOL	INCHES MIN.	INCHES MAX.	MILLIMETERS MIN.	MILLIMETERS MAX.	NOTES
φb	0.027	0.035	0.69	0.89	2
b_1		0.125		3.18	1
φD	0.360	0.400	9.14	10.16	
φD_1	0.245	0.280	6.22	7.11	
φD_2		0.200		5.08	
F		0.075		1.91	
G_1		0.725		18.42	
K	0.220	0.260	5.59	6.60	
1	1.000	1.625	25.40	41.28	
Q		0.025		0.64	
H	0.5		12.7		

NOTES:

1. Dimension to allow for pinch or seal deformation anywhere along tubulation (optional).
2. Diameter to be controlled from free end of lead to within 0.188 inch (4.78 mm) from the point of attachment to the body. Within the 0.188 inch (4.78 mm) dimension, the diameter may vary to allow for lead finishes and irregularities.

TERMINAL CONNECTIONS

Lead No. 1 & Case – Anode
Lead No. 2 – Cathode

RCA

Solid State
Division

Thyristors/Rectifiers

S3705M D2600EF
S3706M D2601DF
D2601EF

These RCA devices are silicon controlled rectifiers and silicon rectifiers intended for use in horizontal-deflection circuits of large-screen color-television receivers. A simplified schematic diagram for the utilization of these SCR's and silicon rectifiers is shown below. For detailed information on the operation of this new deflection circuit, see Application Note AN-3780.

The S3705M (40640)* silicon controlled-rectifier and the D2601EF (40642)* silicon rectifier are the trace circuit components. They provide bipolar switching action for controlling the horizontal yoke current during the picture tube beam-trace interval.

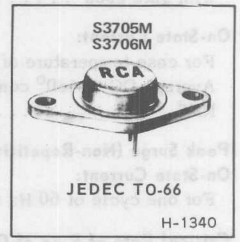
The S3706M (40641)* silicon controlled-rectifier and the D2601DF (40643)* silicon rectifier are the commutating (retrace) circuit components. They control the yoke current during the retrace interval.

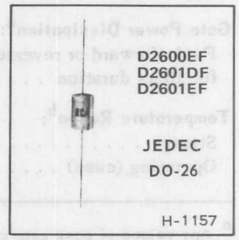
The D2600EF (40644)* silicon rectifier is used as a clamp in the trace circuit to protect the circuit components from excessively high voltages which may result from possible arcing in the picture tube or high-voltage rectifier.

*Numbers in parentheses (e.g. 40640) are former RCA type numbers.

SILICON CONTROLLED-RECTIFIER AND SILICON RECTIFIER COMPLEMENT

For Horizontal Deflection Circuits of Large-Screen Color-TV Receivers





Features:

- **Designed for off-the-line operation: B+ = 155 V**
- **Supply voltages: 108 to 129 V ac**
- **Outstanding performance and reliability**
- **High picture-tube beam current capability: to 1.5mA dc average (max.)**
- **Can fully deflect picture tubes having deflection angles to 90°, 1-7/16" neck diameters, and 25-kV ultor voltages (nom. value)**

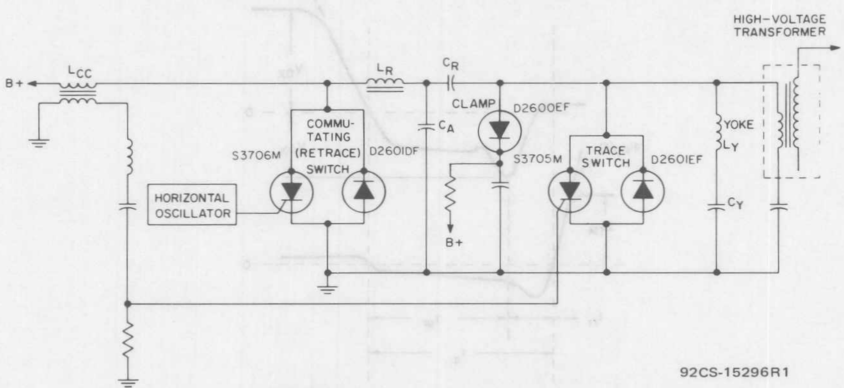


Fig. 1 – Simplified schematic-diagram of horizontal output circuit.

11-73

		SCR	SCR	
Repetitive Peak Off-State Voltage				
With gate open	V_{DROM}	600		V
Repetitive Peak Reverse Voltage				
With gate open	V_{RROM}	5		V
On-State Current:				
For case temperature of +60°C and 60 Hz				
Average DC at 180° conduction angle. . . .	$I_{T(AV)}$	3.2		A
RMS	$I_{T(RMS)}$	5		A
Peak Surge (Non-Repetitive)				
On-State Current:				
For one cycle of 60 Hz voltage	I_{TSM}	80		A
Critical Rate of Rise of On-State Current:				
For $V_{DX} = V_{(BO)O}$ rated value,				
I_{GT} = 50 mA, 0.1µs rise time	di/dt	200		A/µs
Gate Power Dissipation[a]:				
Peak (forward or reverse)				
for 10 µs duration	P_{GM}	25		W
Temperature Range[b]:				
Storage	T_{stg}	-40 to +150		°C
Operating (case)	T_C	-40 to +100		°C

[a] Any values of peak gate current or peak gate voltage to give the maximum gate power are permissible.

[b] For information on the reference point of temperature measurement, see *Dimensional Outline*.

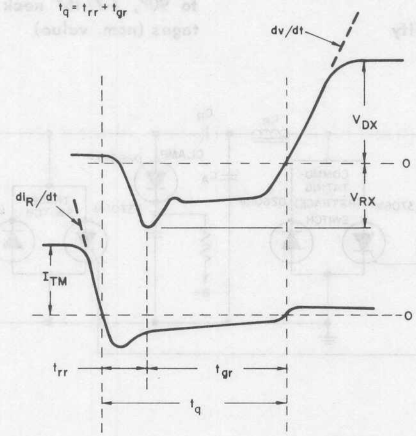


Fig. 2 – Waveshape of t_q characteristic for types S3705M and S3706M.

SILICON CONTROLLED-RECTIFIERS

Characteristics at Maximum Ratings (unless otherwise specified), and at Indicated Case Temperature (T_C)

CHARACTERISTIC:		S3705M Trace SCR Min.	Typ.	Max.	S3706M Commutating SCR Min.	Typ.	Max.	UNIT
Breakover Voltage: With gate open								
At T_C = +100°C	$V_{(BO)O}$	–	–	–	400	–	–	V
At T_C = +80°C	$V_{(BO)O}$	550	–	–	–	–	–	V
Peak Forward Off-State Current: With gate open, $V_{DO} = V_{(BO)O}$ rated value								
At T_C = +100°C	I_{DOM}	–	–	–	–	0.5	1.5	mA
At T_C = +80°C	I_{DOM}	–	0.5	1.5	–	–	–	mA
Instantaneous On-State Voltage: For an on-state current of 30 A, T_C = +25°C	v_T	–	2.2	3	–	2.2	3	V
DC Gate Trigger Current: At T_C = +25°C	I_{GT}	–	15	30	–	15	30	mA(dc)
DC Gate Trigger Voltage: At T_C = +25°C	V_{GT}	–	1.8	4	–	1.8	4	V(dc)
Thermal Resistance: Junction-to-Case	$R_{\theta JC}$	–	–	4	–	–	4	°C/W
Circuit-Commutated Turn-Off Time: (Reverse recovery time + gate recovery time)								
Trace SCR— At I_{TM} = 6 A (t_r = 25 μs, di/dt = 2.5 A/μs), V_D = 0 V (prior to turn on), V_D = 400 V (reapplied at 175 V/μs), V_R = 0.8 V (min.), I_{GT} = 100 mA, V_{GK}(bias) = -30 V (68 Ω source), f = 15.75 kHz, T_C = 70°C	t_q	–	–	2.5	–	–	–	μs
Commutating SCR— At I_{TM} = 13 A (½ sine wave 7 μs base, initial di/dt = 20 A/μs to 3 A), V_D = 350 V (prior to turn on), dV/dt = 400 V/μs (to 100 V), V_R = 0.8 V (min.) I_{GT} = 100 mA (t_p = 3 μs, t_r = 0.2 μs), V_{GK}(bias) = -2.5 V (47 Ω source during turn off), f = 15.75 kHz, T_C = 70°C	t_q	–	–	–	–	–	4.5	μs

SILICON RECTIFIERS

MAXIMUM RATINGS:

		D2601EF *Trace*	D2601DF *Commutating*	D2600EF *Clamp*	
			Silicon Rectifiers		
Non-Repetitive Peak Reverse Voltage[c]	$V_{RM}(nonrep)$	700	800	700	V
Repetitive Peak Reverse Voltage[d]	$V_{RM}(rep)$	550	450	550	V
Forward Current:[d]					
DC	I_F	1	1	1	A
RMS	$I_{F(RMS)}$	1.9	1.6	0.2	A
Peak Repetitive	$I_{FM(rep)}$	6.5	6	0.3	A
Peak Surge[e]	$I_{FM(surge)}$	70	10	20	A
Ambient Temperature Range:					
Operating	T_A		-40 to +150		^{o}C
Storage	T_{stg}		-40 to +175		^{o}C
Lead Temperature:					
For 10 seconds maximum			255		^{o}C

CHARACTERISTICS:

		D2601EF	D2601DF	D2600EF		
Max. Instantaneous Forward Voltage Drop:						
At I_F = 4 A, $T_A \leq 75^{o}C$	v_{FM}	1.3	1.3	2		V
Max. Reverse Current (Static):[f]						
At T_C = 100°C	I_{RM}	0.25	0.25	0.25		mA
At T_A = 25°C	I_{RM}	10	10	10		µA
Reverse Recovery Time:						
At I_F = 20 mA, I_R = 1 mA, T_C = 25°C	t_{rr}	1.1	1.1	1.6	max	µs
Turn-On Time:						
At I_F = 20 mA, T_C = 25°C	t_{on}	0.3	0.3	0.3	max	µs
Peak Turn-On Voltage:						
At I_F = 20 mA, T_C = 25°C		5	6	7	max	V

[c] Pulse width = 10 µs, pulse repetition rate = 15.7 kHz, 3 pulses.

[d] For ambient temperatures up to 45°C and maximum thermal resistance from reference point to ambient of 45°C/W, with devices operating in circuit of Fig.1.

[e] Pulse width = 3 ms.

[f] At max. peak reverse voltage and zero forward current.

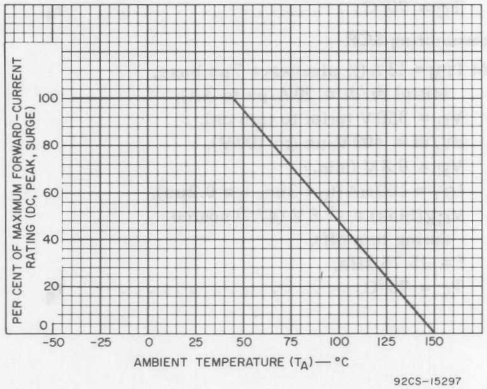
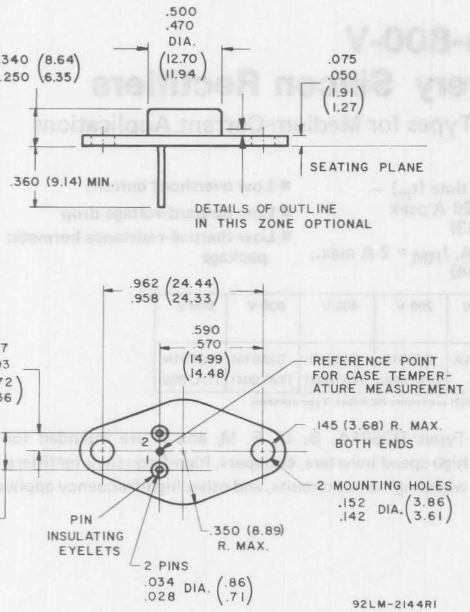


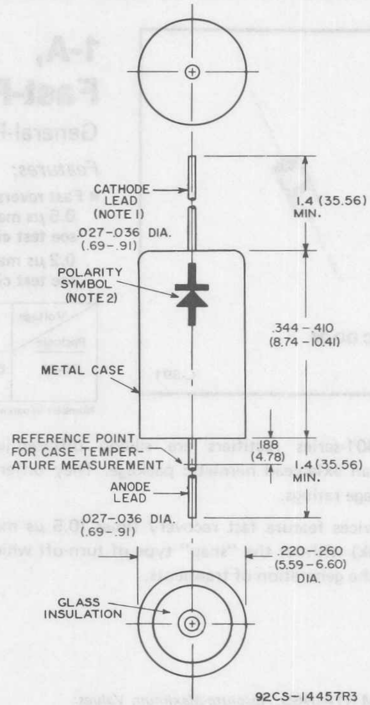
Fig. 3 – Rating chart for types D2600EF, D2601DF, and D2601EF.

DIMENSIONAL OUTLINES

S3705M, S3706M
JEDEC TO-66



D2600EF, D2601DF, D2601EF
JEDEC DO-26



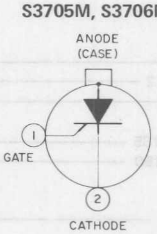
Note 1: Connected to metal case.

Note 2: Arrow indicates direction of forward (easy) current flow as indicated by dc ammeter.

Dimensions in parentheses are in millimeters and are derived from the basic inch dimensions as indicated.

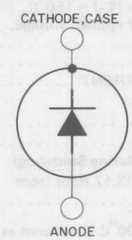
TERMINAL DIAGRAMS

S3705M, S3706M



Pin 1: Gate
Pin 2: Cathode
Case: Anode

D2600EF, D2601DF, D2601EF



RCA
Solid State Division

Rectifiers

D2601A D2601F
D2601B D2601M
D2601D D2601N

JEDEC DO-26

L-391

1-A, 50-to-800-V Fast-Recovery Silicon Rectifiers

General-Purpose Types for Medium-Current Applications

Features:

- **Fast reverse-recovery time (t_{rr}) – 0.5 μs max. (I_{FM} = 20 A peak see test circuit Fig. 13) 0.2 μs max. (I_F = 1 A, I_{RM} = 2 A max., see test circuit Fig. 14)**
- **Low overshoot current**
- **Low forward-voltage drop**
- **Low-thermal-resistance hermetic package**

Voltage / Package	50 V	100 V	200 V	400 V	600 V	800 V
DO-26	D2601F –	D2601A –	D2601B (TA7892)	D2601D (TA7893)	D2601M (TA7894)	D2601N (TA7895)

Numbers in parentheses (e.g. TA7892) are former RCA-Dev. Type numbers

RCA-D2601-series rectifiers are silicon diffused-junction-types in an axial-lead hermetic package. They differ only in their voltage ratings.

These devices feature fast recovery times (0.5 μs max. from 20 A peak) without the "snap" type of turn-off which could result in the generation of transients.

Types D2601A, B, D, F, M, and N are intended for use in high-speed inverters, choppers, high-frequency rectifiers, "free-wheeling" diode circuits, and other high-frequency applications.

MAXIMUM RTAINGS, *Absolute-Maximum Values:*

		D2601F	D2601A	D2601B	D2601D	D2601M	D2601N	
REVERSE VOLTAGE:								
REPETITIVE PEAK	V_{RRM}	50	100	200	400	600	800	V
NON-REPETITIVE PEAK	V_{RSM}	100	200	300	500	700	1000	V
FORWARD CURRENT:•								
Conduction angle = 180°, half-sine-wave								
RMS	$I_{F(RMS)}$	← 1.5 →						A
Average	I_o	← 1 →						A
PEAK-SURGE (NON-REPETITIVE) CURRENT:								
At junction temperature (T_J) = 150°C								
For one-half cycle of applied voltage, 60 Hz (8.3 ms)		← 35 →						A
For other durations		← See Fig. 2 →						
PEAK (REPETITIVE) CURRENT	I_{FRM}	← 6 →						A
TEMPERATURE RANGE:								
Storage	T_{stg}	← −40 to 165 →						°C
Operating (Junction)	T_J	← −40 to 150 →						°C
LEAD TEMPERATURE (During Soldering):	T_L							
At a distance of 1/8 in. (3.17 mm) from case for 10 s max.		← 225 →						°C

• At lead temperature of 100°C (measured at point of anode lead 1/32 in. (0.031 mm) from the case).

ELECTRICAL CHARACTERISTICS

CHARACTERISTIC	SYMBOL	LIMITS ALL TYPES MIN.	MAX.	UNITS
Reverse Current: *Static* For V_{RRM} = max. rated value, $I_F = 0$, $T_J = 25°C$	I_{RM}	–	15	μA
$T_J = 100°C$		–	250	
Dynamic		See Fig. 9		
Instantaneous Forward Voltage Drop: At $i_F = 4$ A, $T_J = 25°C$ (See Fig. 3)	v_F	–	1.9	V
Reverse Recovery Time: For circuit shown in Fig. 13, at $I_{FM} = 20$ A, $-di_F/dt = -20$ A/μs, plus duration = 2.8 μs, $T_C = 25°C$	t_{rr}	–	0.5	μs
For circuit shown in Fig. 14, at $I_F = 1$ A, $I_{RM} = 2$ max., $T_C = 25°C$		–	0.2	
Thermal Resistance (Junction-to-Case)■	$R_{\theta JC}$	–	39	°C/W

■Measured at point on anode lead 1/32 in. (0.031 mm) from case.

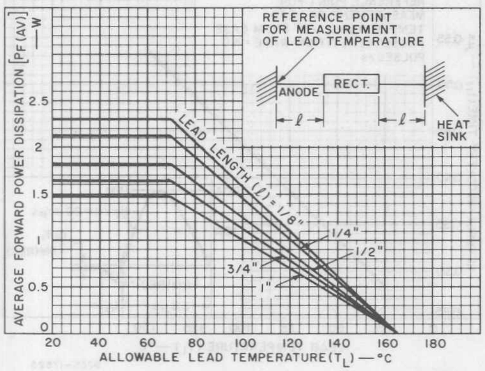


Fig. 1 — Average forward-power dissipation vs. lead temperature.

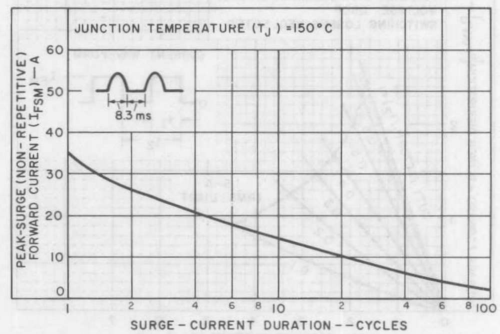


Fig. 2 — Peak-surge (non-repetitive) forward current vs. surge-current duration.

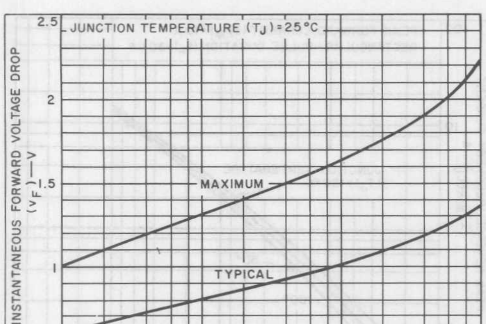


Fig. 3 — Forward-voltage drop vs. forward current.

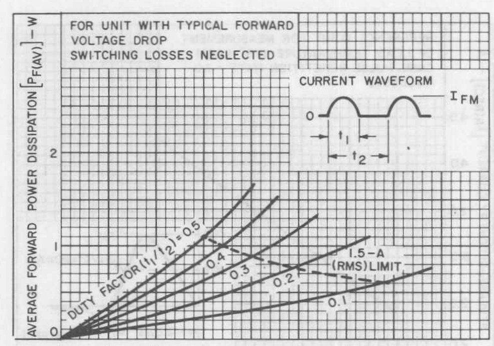


Fig. 4 — Average forward power dissipation as a function of peak current and duty factor for units with typical forward voltage drop.

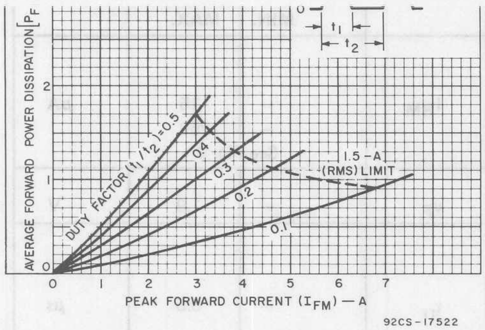


Fig. 5 — Average forward power dissipation as a function of peak current and duty factor for units with maximum forward voltage drop.

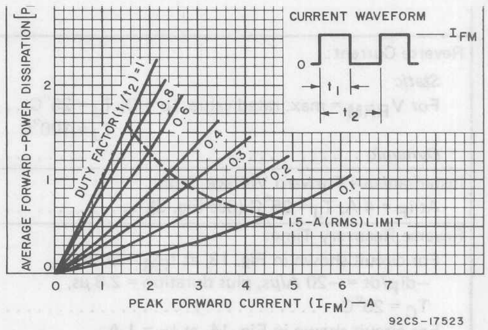


Fig. 6 — Average forward power dissipation as a function of peak current and duty factor for units with typical forward voltage drop.

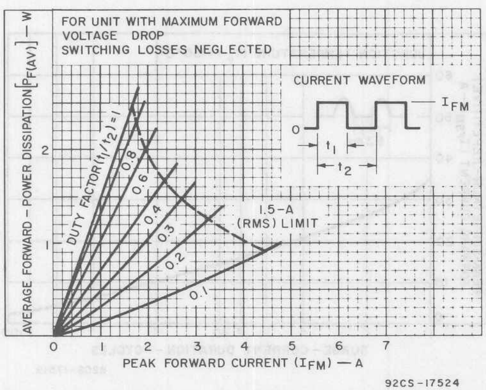


Fig. 7 — Average forward power dissipation as a function of peak current and duty factor for units with maximum forward voltage drop.

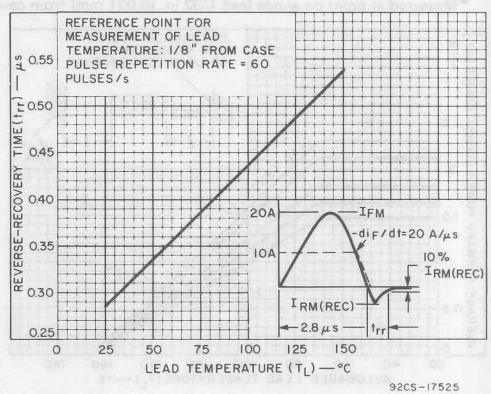


Fig. 8 — Typical variation of reverse-recovery time with lead temperature.

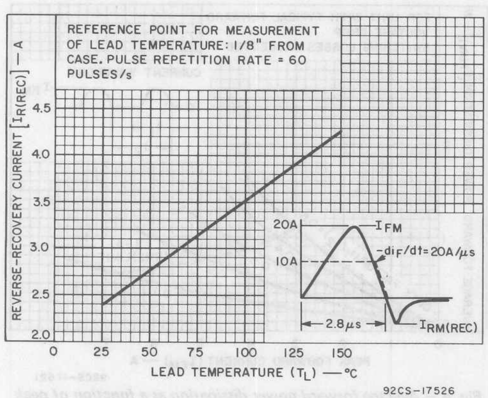


Fig. 9 — Reverse-recovery current vs. lead temperature.

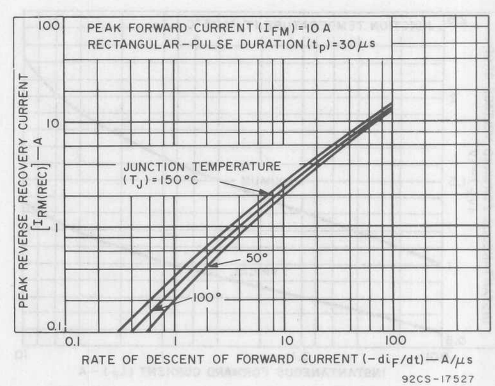


Fig. 10 — Peak reverse-recovery current vs. rate of descent of forward current.

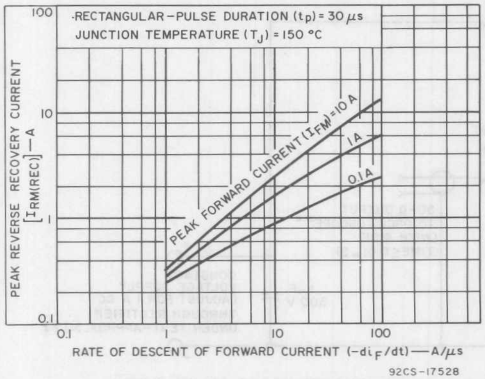


Fig. 11 — Peak reverse-recovery current vs. rate of descent of forward current.

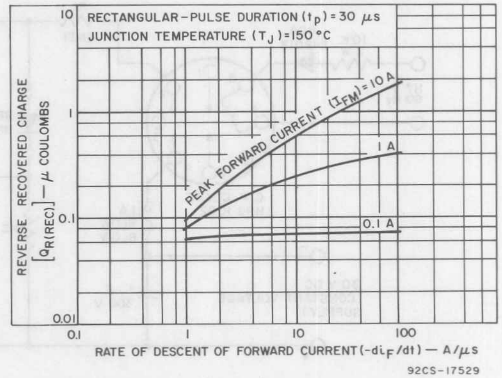


Fig. 12 — Reverse-recovered charge vs. rate of descent of forward current.

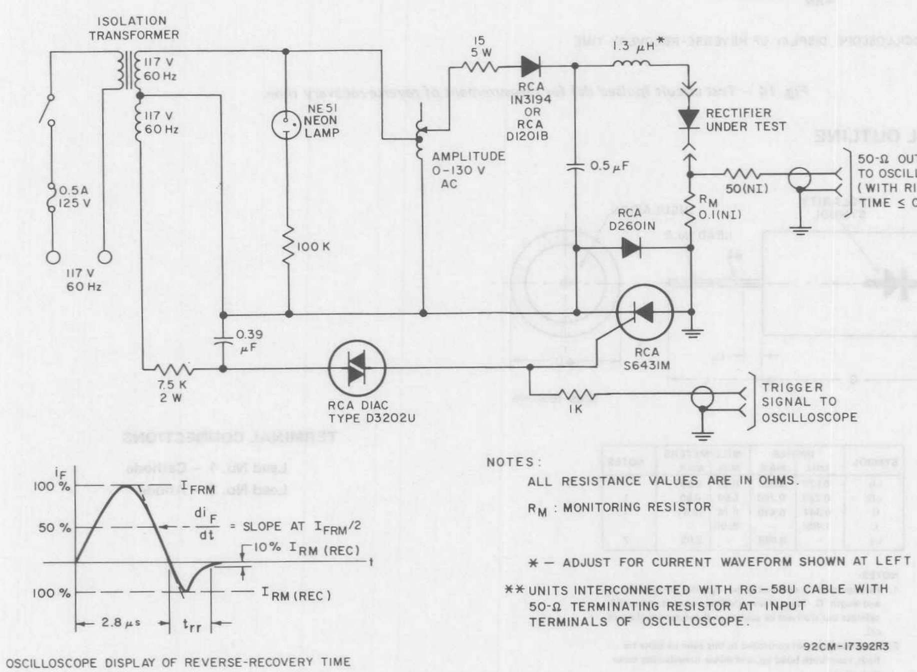


Fig. 13 — Test circuit (pulsed sine wave) for measurement of reverse-recovery time.

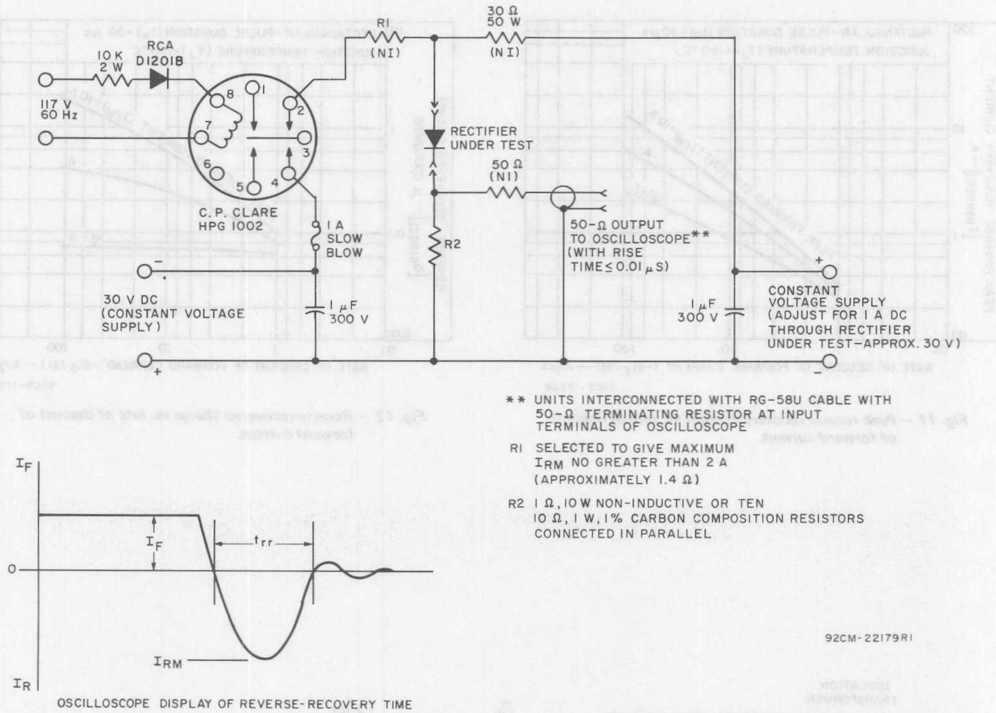
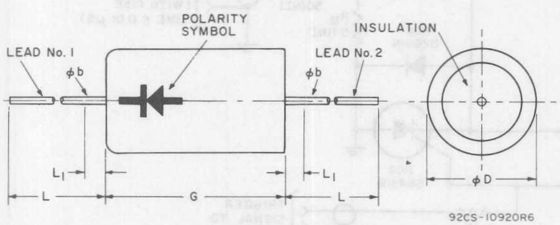


Fig. 14 — Test circuit (pulsed dc) for measurement of reverse-recovery time.

DIMENSIONAL OUTLINE
JEDEC DO-26



SYMBOL	INCHES MIN.	INCHES MAX.	MILLIMETERS MIN.	MILLIMETERS MAX.	NOTES
φb	0.027	0.039	0.69	0.99	
φD	0.220	0.260	5.59	6.60	1
G	0.344	0.410	8.74	10.41	1
L	1.400	–	35.56	–	
L_1	–	0.080	–	2.03	2

NOTES:

1. Package contour optional within cylinder of diameter φD and length G. Slugs, if any, shall be included within this cylinder but shall not be subject to the minimum limit of φD.
2. Lead diameter not controlled in this zone to allow for flash, lead-finish build up, and minor irregularities other than slugs.

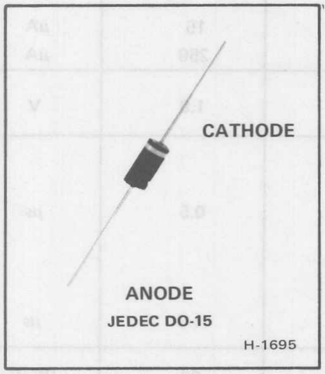
TERMINAL CONNECTIONS

Lead No. 1 — Cathode
Lead No. 2 — Anode

RCA
Solid State
Division

Rectifiers

D2201 Series



1-A, 50-to-800-V Fast-Recovery Silicon Rectifiers

General-Purpose Types for
Medium-Current Applications

Features:

- **Fast turn-off: 0.5 μs max. from 3.14-A peak**
- **Low overshoot current**
- **Low forward voltage drop**

RCA D2201 Series devices are diffused-junction silicon rectifiers in an axial-lead package. These devices, which differ only in their voltage ratings, feature fast recovery times (0.5 μs max. from 3.14 A peak) without the "snap" type of turn-off which could result in the generation of transients.

The D2201 series are intended for use in high-speed inverters, choppers, high-frequency rectifiers, "free-wheeling" diode circuits, and other high-frequency applications.

MAXIMUM RATINGS, *Absolute-Maximum Values:*

		D2201F (44933)*	D2201A (44934)*	D2201B (44935)*	D2201D (44936)*	D2201M (44937)*	D2201N (44938)*	
REVERSE VOLTAGE:								
REPETITIVE PEAK	V_{RRM}	50	100	200	400	600	800	V
NON-REPETITIVE PEAK	V_{RSM}	100	150	300	500	700	1000	V
FORWARD CURRENT:●								
RMS	$I_{F(RMS)}$	1.5						A
AVERAGE:								
For 180° conduction angle, half sine wave	I_o	1						A
PEAK SURGE (NON-REPETITIVE):								
At junction temperature (T_J) = 150°C								
For one-half cycle of applied voltage, 60 Hz (8.3 ms)	I_{FSM}	50						A
For other durations		See Fig. 3						
PEAK (REPETITIVE)	I_{FRM}	6						A
STORAGE-TEMPERATURE RANGE		−40 to +165						°C
OPERATING (JUNCTION) TEMPERATURE		150						°C
LEAD TEMPERATURE (During Soldering):								
Measured 1/8 in. (3.17 mm) from case for 10 s max.		255						°C

*Number in parentheses is a former RCA type number.
●At lead temperature of 100°C (measured at point on anode lead 1/32 in. (0.8 mm) from the case).

CHARACTERISTIC	SYMBOL	All Types Min.	All Types Max.	UNITS
Reverse Current:				
Static:				
For V_{RRM} = max. rated value, $I_F = 0$,	I_{RM}			
$T_J = 25^oC$		–	15	μA
$T_J = 100^oC$		–	250	μA
Instantaneous Forward Voltage Drop:				
At $i_F = 4$ A, $T_J = 25^oC$ See Fig. 4.	v_F	–	1.9	V
Reverse Recovery Time:				
For circuit shown in Fig. 1:				
At $I_{FM} = 3.14$ A, $-di_F/dt = 10$ A/μs, pulse duration = 9.4 μs, $T_C = 25^oC$	t_{rr}	–	0.5	μs
In Tektronix type "S" plug-in unit: At $I_F = 20$ mA, $I_R = 1.0$ mA (DC values) $T_C = 25^oC$		–	1.5	μs
Thermal Resistance (Junction-to-Lead)* See Fig. 14	$R_{\theta JL}$	–	20	$^oC/W$

* Measured on anode lead 1/8" (3.18 mm) from case.

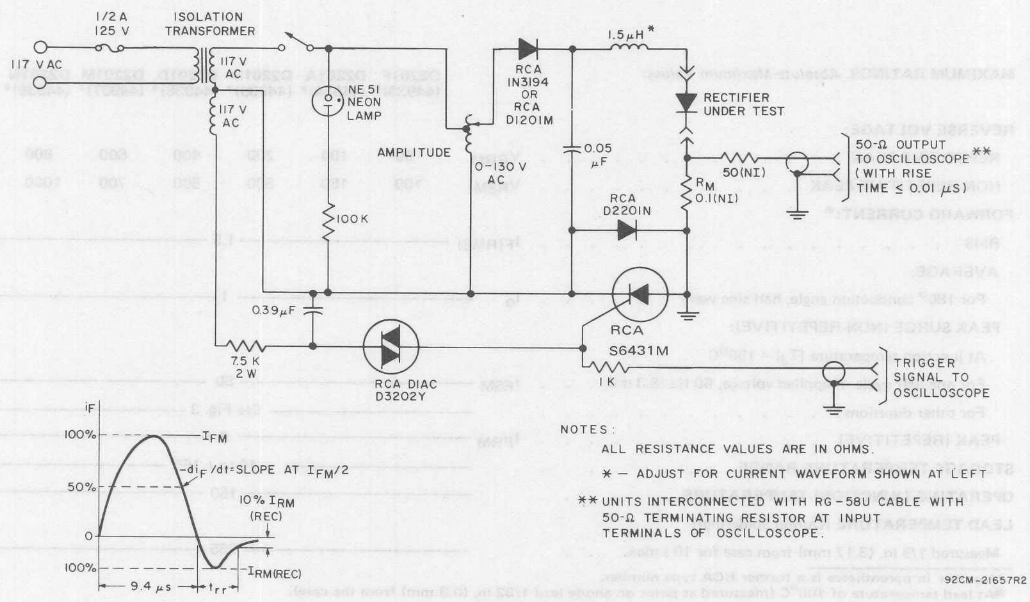


Fig.1 – Oscilloscope display and test circuit for measurement of reverse-recovery time for all types.

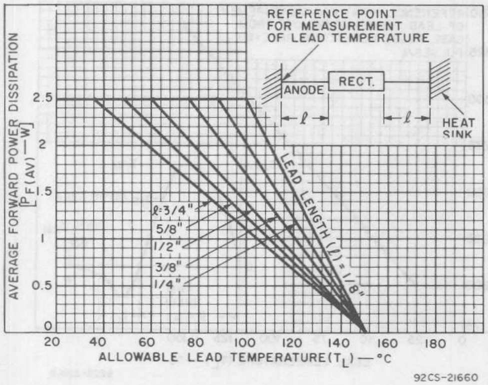


Fig.2 – Average forward power dissipation vs. lead temperature for all types.

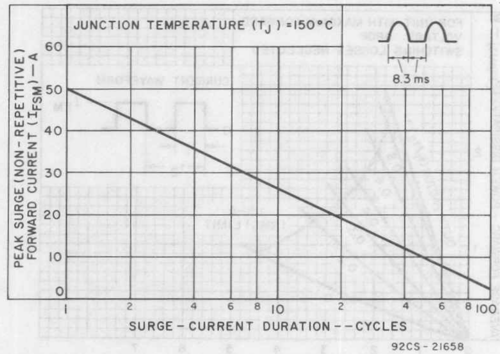


Fig.3 – Peak surge (non-repetitive) forward current vs. surge-current duration for all types.

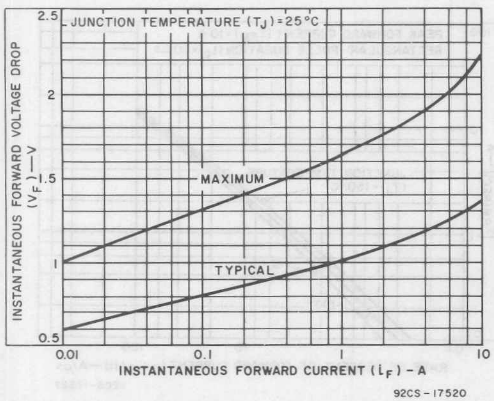


Fig.4 – Forward voltage drop vs. forward current for all types.

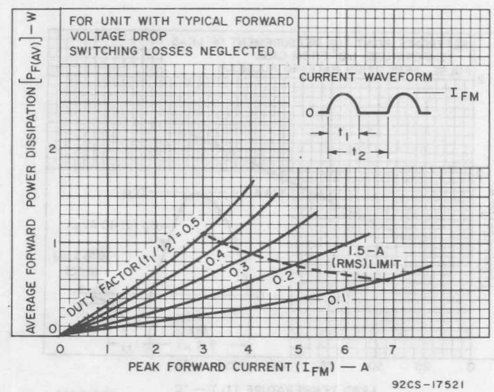


Fig.5 – Average forward power dissipation (typical) as a function of duty factor for all types.

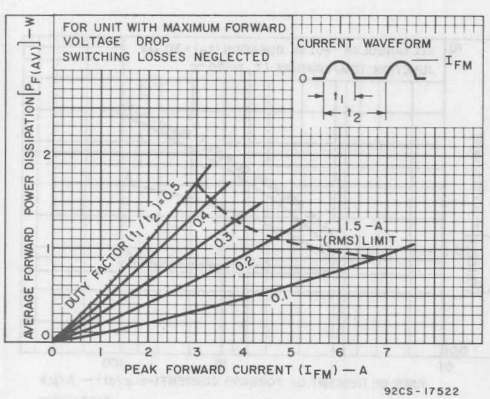


Fig.6 – Average forward power dissipation (maximum) as a function of duty factor for all types.

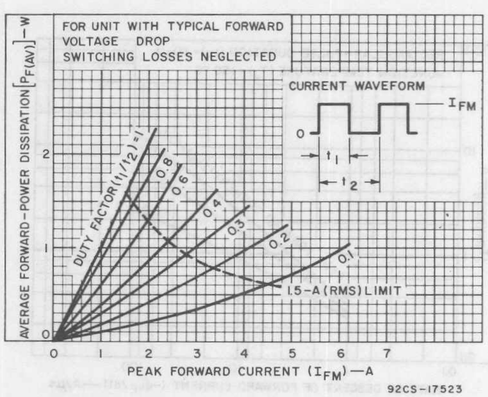


Fig.7 – Average forward power dissipation (typical) as a function of duty factor for all types.

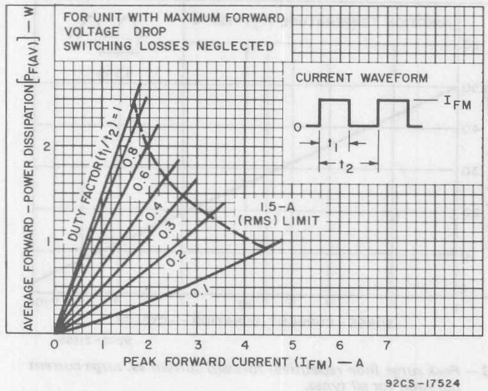


Fig.8 — Average forward power dissipation (maximum) as a function of duty factor for all types.

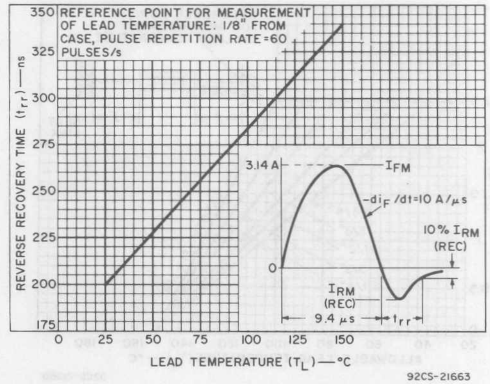


Fig.9 — Typical variation of reverse recovery time with lead temperature for all types.

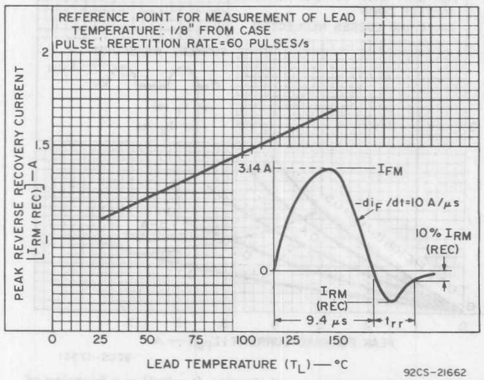


Fig.10 — Peak reverse recovery current vs. lead temperature for all types.

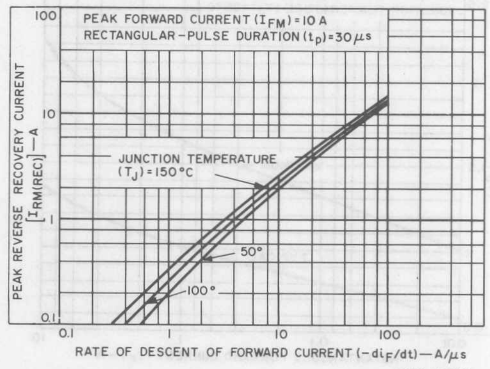


Fig.11 — Peak reverse recovery current vs. rate of descent of forward current for all types.

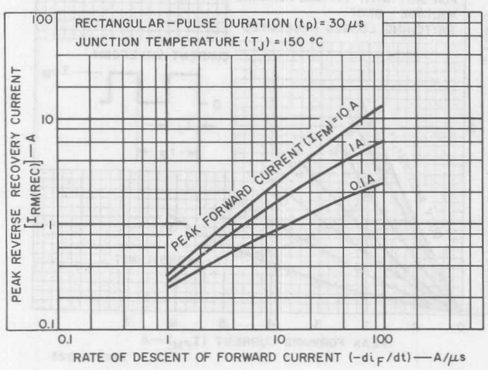


Fig.12 — Peak reverse recovery current vs. rate of descent of forward current for all types.

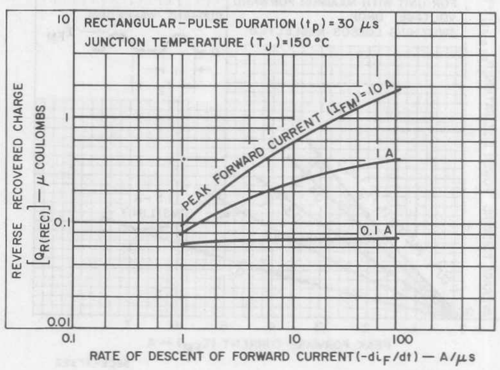


Fig.13 — Reverse recovered charge vs. rate of descent of forward current for all types.

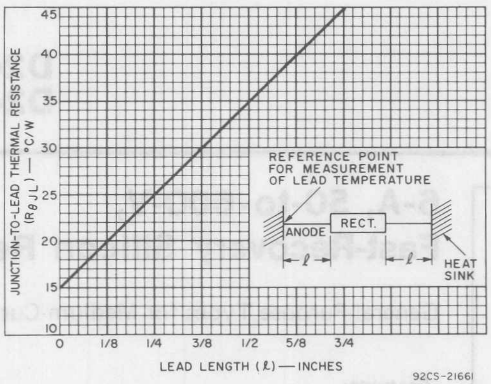
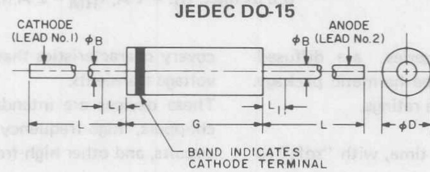


Fig.14 — Junction-to-lead thermal resistance vs. lead length for all types.

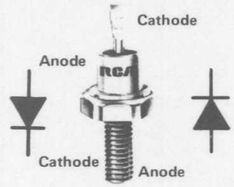
DIMENSIONAL OUTLINE JEDEC DO-15



SYMBOL	INCHES		MILLIMETERS		NOTES
	MIN.	MAX.	MIN.	MAX.	
φB	0.030	0.034	0.762	0.863	–
φD	0.133	0.137	3.378	3.479	1
G	0.280	0.285	7.112	7.239	1
L	1.000	–	25.40	–	–
L_1	–	0.050	–	1.27	2

NOTES

1. Package contour optional within cylinder of diameter φD and length G. Slugs, if any, shall be included within this cylinder but shall not be subject to the minimum limit of φD.
2. Lead diameter not controlled in this zone to allow for flash, lead-finish build-up, and minor irregularities other than slugs.



Forward-polarity (D2406 series)

Reverse-polarity (D2406-R series)

JEDEC DO-4

H-1167

6-A, 50-to-600-V, Fast-Recovery Silicon Rectifiers

General-Purpose Types for Medium-Current Applications

Features:

- **Available in reverse-polarity versions: D2406A-R, D2406B-R, D2406C-R, D2406D-R, D2406F-R, D2406M-R**
- Fast reverse-recovery time (t_{rr}) —
  0.35 μs max. (I_{FRM} = 19 A peak, see test circuit Fig.1)
  0.2 μs max. (I_F = 1 A, I_{RM} = 2 A max., see test circuit Fig.2)
- Low reverse-recovery current
- Low forward-voltage drop
- Low-thermal-resistance hermetic package

RCA D2406 series and D2406-R series are diffused-junction silicon rectifiers in a stud-type hermetic package. These devices differ only in their voltage ratings.

All types feature fast reverse-recovery time, with "soft" recovery characteristics that reduce the generation of RFI and voltage transients.

These devices are intended for use in high-speed inverters, choppers, high-frequency rectifiers, "free-wheeling" diode circuits, and other high-frequency applications.

MAXIMUM RATINGS, *Absolute-Maximum Values:*

		D2406F (43879)* D2406F-R (43879R)*	D2406A (43880)* D2406A-R (43880R)*	D2406B (43881)* D2406B-R (43881R)*	D2406C (43882)* D2406C-R (43882R)*	D2406D (43883)* D2406D-R (43883R)*	D2406M (43884)* D2406M-R (43884R)*	
REVERSE VOLTAGE:								
Repetitive peak	V_{RRM}	50	100	200	300	400	500	V
Non-repetitive peak	V_{RSM}	100	200	300	400	600	800	V
FORWARD CURRENT (Conduction angle = 180°, half sine wave):								
RMS (T_C = 100°C)●	$I_{F(RMS)}$	9						A
Average (T_C = 100°C)●	I_o	6						A
Peak-surge (non-repetitive):	I_{FSM}							
At junction temperature (T_J) = 150°C:								
For one-half cycle of applied voltage, 60 Hz (8.3 ms)		125						A
For other durations		See Fig.3						
Peak (repetitive)	I_{FRM}	25						A
STORAGE-TEMPERATURE RANGE		−40 to 165						°C
OPERATING (JUNCTION) TEMPERATURE		150						°C
STUD TORQUE:								
Recommended		15						in-lb
Maximum (DO NOT EXCEED)		25						in-lb

* Number in parentheses is a former RCA type number.

● Case temperature is measured at center of any flat surface on the hexagonal head of the mounting stud.

ELECTRICAL CHARACTERISTICS

CHARACTERISTIC	SYMBOL	LIMITS ALL TYPES MIN.	MAX.	UNITS
Reverse Current: *Static* For V_{RRM} = max. rated value, I_F = 0, T_C = 25°C	I_{RM}	–	15	μA
T_C = 100°C		–	3	mA
Instantaneous Forward Voltage Drop: At i_F 6 A, T_J = 25°C	v_F	–	1.4	V
Reverse Recovery Time: For circuit shown in Fig. 1, at I_{FM} = 19 A, $-di_F/dt$ = 25 A/μs, pulsed duration = 2.25 μs, T_C = 25°C	t_{rr}	–	0.35	μs
For circuit shown in Fig. 2, at I_{FM} = 1 A, I_{RM} = 2 A max., T_C = 25°C		–	0.2	
Thermal Resistance (Junction-to-Case)	$R_{\theta JC}$	–	3	°C/W

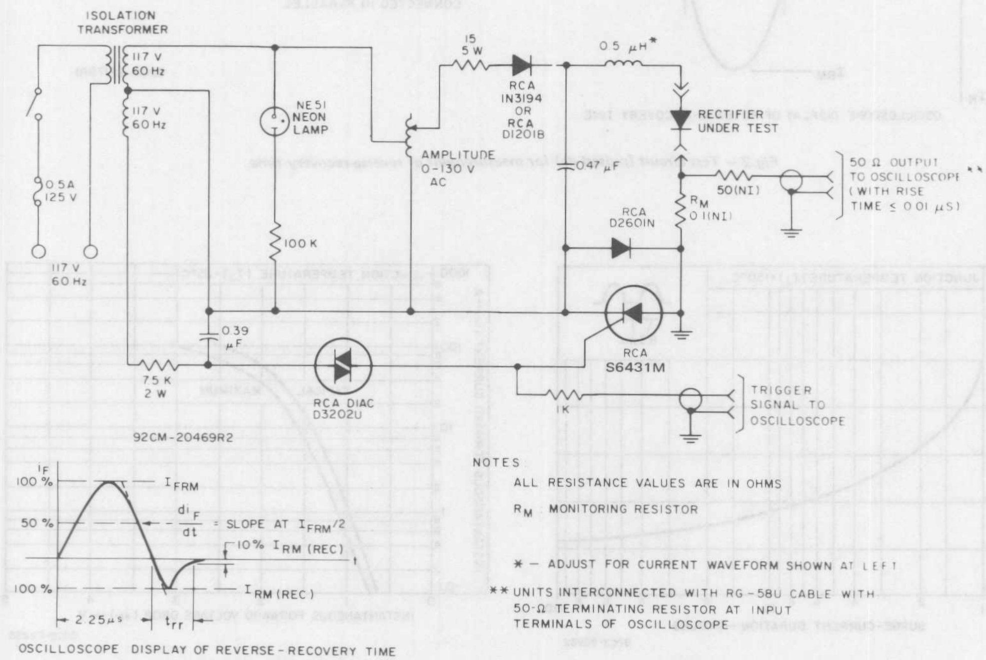


Fig.1 – Test circuit (pulsed sine wave) for measurement of reverse-recovery time.

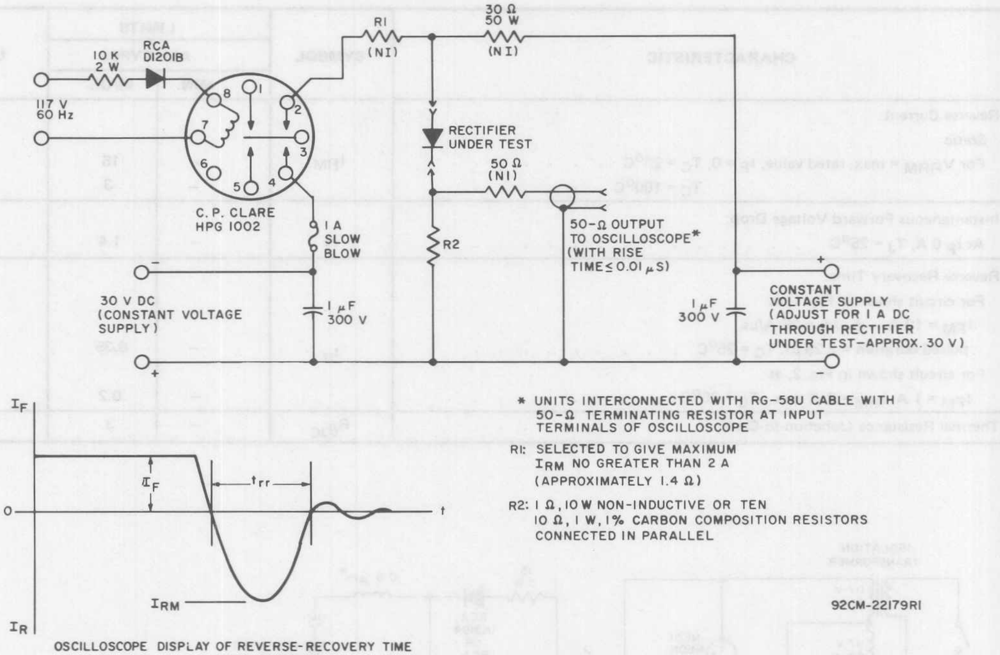


Fig.2 – Test circuit (pulsed dc) for measurement of reverse-recovery time.

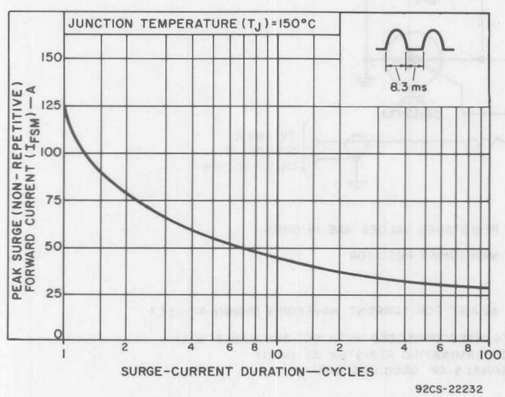


Fig.3 – Peak surge (non-repetitive) forward current vs. surge-current duration.

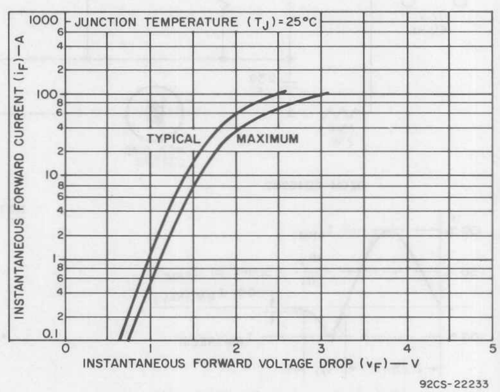


Fig.4 – Forward current vs. forward voltage drop.

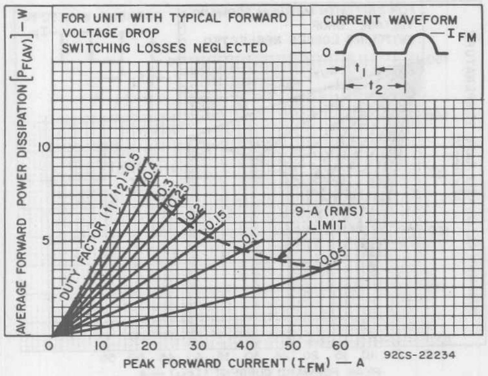


Fig.5 – Average forward power dissipation as a function of peak current and duty factor for units with typical forward voltage drop.

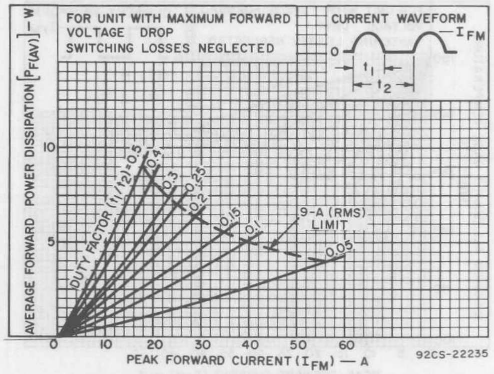


Fig.6 – Average forward power dissipation as a function of peak current and duty factor for units with maximum forward voltage drop.

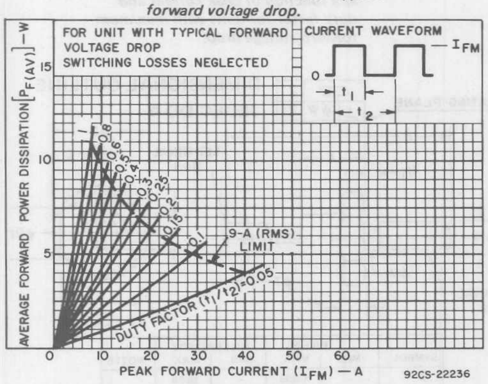


Fig.7 – Average forward power dissipation as a function of peak current and duty factor for units with typical forward voltage drop.

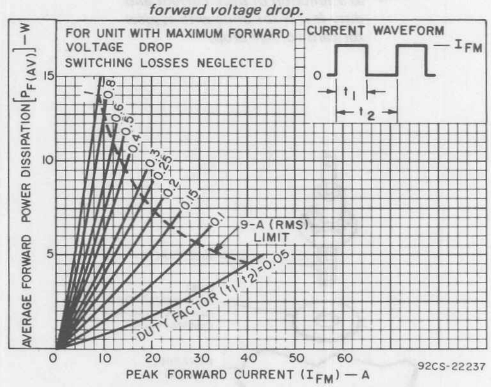


Fig.8 – Average forward power dissipation as a function of peak current and duty factor for units with maximum forward voltage drop.

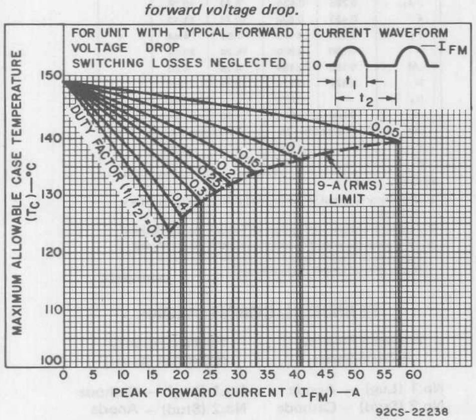


Fig.9 – Maximum allowable case temperature as a function of peak current and duty factor for units with typical forward voltage drop.

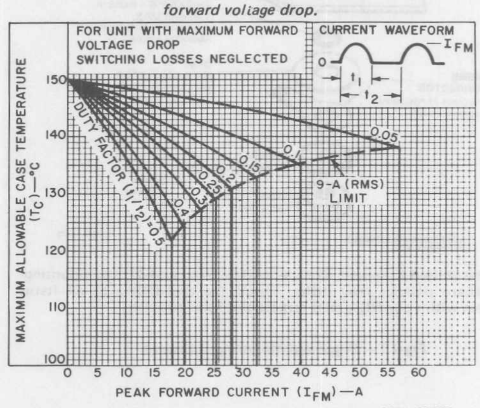


Fig.10 – Maximum allowable case temperature as a function of peak current and duty factor for units with maximum forward voltage drop.

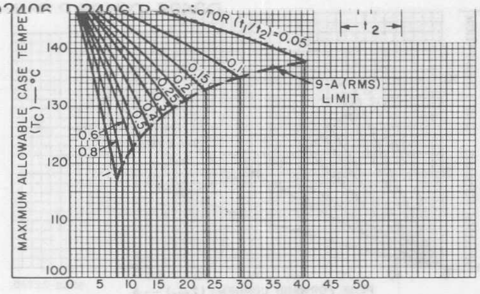


Fig.11 – Maximum allowable case temperature as a function of peak current and duty factor for units with typical forward voltage drop.

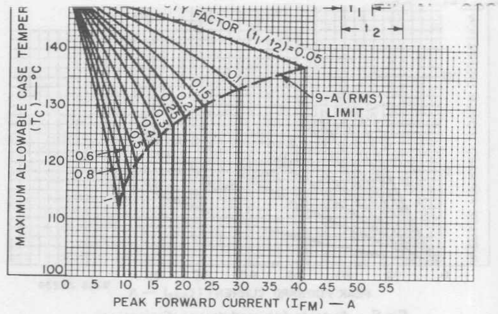
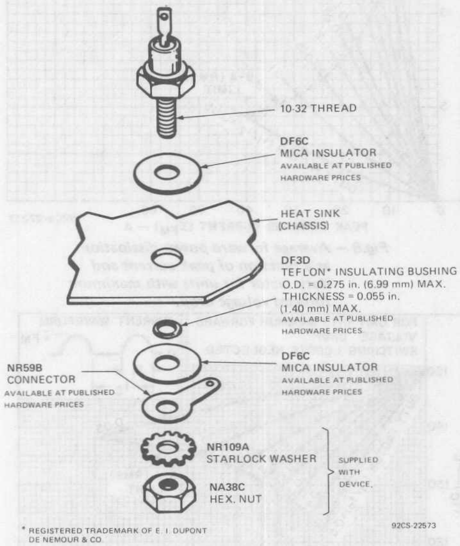


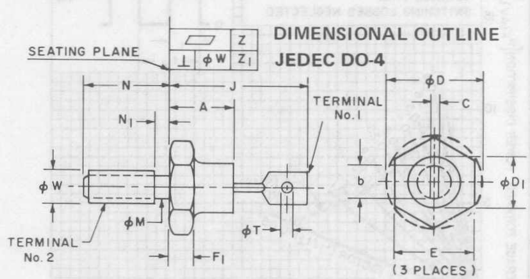
Fig.12 – Maximum allowable case temperature as a function of peak current and duty factor for units with maximum forward voltage drop.



In the United Kingdom, Europe, Middle East, and Africa, mounting-hardware policies may differ; check the availability of all items shown with your RCA sales representative or supplier.

Fig.13 – Suggested mounting hardware.

DIMENSIONAL OUTLINE JEDEC DO-4



SYMBOL	INCHES MIN.	INCHES MAX.	MILLIMETERS MIN.	MILLIMETERS MAX.	NOTES
A	–	0.405	–	10.28	
b	–	0.250	–	6.35	2
c	0.020	0.065	0.51	1.65	
ϕD	–	0.505	–	12.82	
ϕD_1	0.265	0.424	6.74	10.76	
E	0.423	0.438	10.75	11.12	
F_1	0.075	0.175	1.91	4.44	1
J	0.600	0.800	15.24	20.32	
ϕM	0.163	0.189	4.15	4.80	
N	0.422	0.453	10.72	11.50	
N_1	–	0.078	–	1.98	
ϕT	0.060	0.095	1.53	2.41	
ϕW	10-32 UNF-2A		10-32 UNF-2A		3
Z	–	0.002	–	0.050	
Z_1	–	0.006	–	0.152	

NOTES:

1: Chamfer or undercut on one or both sides of hexagonal base is optional.

2: Angular orientation and contour of Terminal No. 1 is optional.

3: ϕW is pitch diameter of coated threads. REF: Screw Thread Standards for Federal Services, Handbook H 28 Part I. Recommended torque: 15 inch-pounds.

92CS-20472

TERMINAL CONNECTIONS

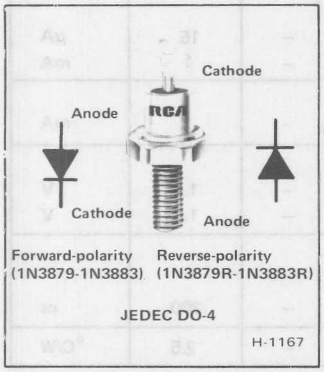
Forward Polarity (D2406 Series)	Reverse Polarity (D2406-R Series)
No.1 (Lug) – Anode	No.1 (Lug) – Cathode
No.2 (Stud) – Cathode	No.2 (Stud) – Anode

When incorporating RCA Solid State Devices in equipment, it is recommended that the designer refer to "Operating Considerations for RCA Solid State Devices", Form No. 1CE-402, available on request from RCA Solid State Division, Box 3200, Somerville, N.J. 08876.

RCA
Solid State
Division

Rectifiers

1N3879–1N3883
1N3879R–1N3883R



6-A, 50-to-400-V, Fast-Recovery Silicon Rectifiers

General-Purpose Types for High-Current Applications

Features:

- Available in reverse-polarity versions: 1N3879R, 1N3880R, 1N3881R, 1N3882R, 1N3883R
- Fast reverse-recovery time (t_{rr}) – 200 ns max. (I_F = 1 A, I_{RM} = 2 A max., see test circuit Fig. 2)
- Low reverse-recovery current
- Low forward-voltage drop
- Low-thermal-resistance hermetic package

For data on other RCA fast recovery rectifiers, refer to the following RCA data bulletins:
6-A File No. 663 (D2406 Series)
12-A File No. 664 (D2412 Series)
20-A File No. 665 (D2520 Series)
40-A File No. 580 (D2540 Series)

RCA types 1N3879 – 1N3883 and 1N3879R – 1N3883R are diffused-junction silicon rectifiers in a stud-type hermetic package. These devices differ only in their voltage ratings.

All types feature fast reverse-recovery time of 200 ns max. These devices are intended for use in high-speed inverters, choppers, high-frequency rectifiers, "free-wheeling" diode circuits, and other high-frequency applications

MAXIMUM RATINGS, *Absolute-Maximum Values:*

		1N3879 1N3879R	1N3880 1N3880R	1N3881 1N3881R	1N3882 1N3882R	1N3883 1N3883R	
REVERSE VOLTAGE:							
*Repetitive peak	V_{RRM}	50	100	200	300	400	V
Non-repetitive peak	V_{RSM}	75	200	300	400	500	V
*DC (Blocking)	V_R	50	100	200	300	400	V
FORWARD CURRENT (Conduction angle = 180°, half sine wave):							
RMS (T_C = 100°C)▲	$I_{F(RMS)}$			9			A
* Average (T_C = 100°C)▲	I_o			6			A
* Peak-surge (non-repetitive):	I_{FSM}						
At junction temperature (T_J) = 150°C:							
For one cycle of applied voltage, 60 Hz				75			A
For ten cycles of applied voltage, 60 Hz				35			A
Peak (repetitive)	I_{FRM}			25			A
*STORAGE-TEMPERATURE RANGE	T_{stg}			–65 to 175			°C
*OPERATING (JUNCTION) TEMPERATURE	T_J			–65 to 150			°C
STUD TORQUE:	τ_s						
*Recommended				15			in-lb
Maximum (DO NOT EXCEED)				25			in-lb

*In accordance with JEDEC registration data.

▲Case temperature is measured at center of any flat surface on the hexagonal head of the mounting stud.

ELECTRICAL CHARACTERISTICS

	CHARACTERISTIC	SYMBOL	LIMITS ALL TYPES MIN.	LIMITS ALL TYPES MAX.	UNITS
*	Reverse Current:				
	Static				
	For V_{RRM} = max. rated value, I_F = 0, T_C = 25°C	I_{RM}	–	15	µA
	T_C = 100°C		–	1	mA
	Dynamic				
	For single phase full cycle average, I_o = 6 A, T_C = 100°C	$I_{R(AV)}$	–	3	mA
*	Instantaneous Forward Voltage Drop:				
	At i_F = 6 A, V_{RRM} = rated value, T_J = 100°C	$v_{F(PK)}$	–	1.5	V
	At i_F = 6 A, T_J = 25°C	v_F	–	1.4	V
*	Reverse Recovery Time:				
	For circuit shown in Fig. 2, at				
	I_{FM} = 1 A, I_{RM} = 2 A max., T_C = 25°C	t_{rr}	–	200	ns
	Thermal Resistance (Junction-to-Case)	$R_{\theta JC}$	–	2.5	°C/W

*In accordance with JEDEC registration data.

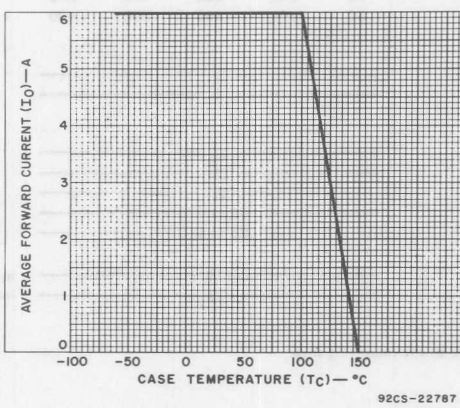


Fig.1 — Average forward current vs. case temperature.

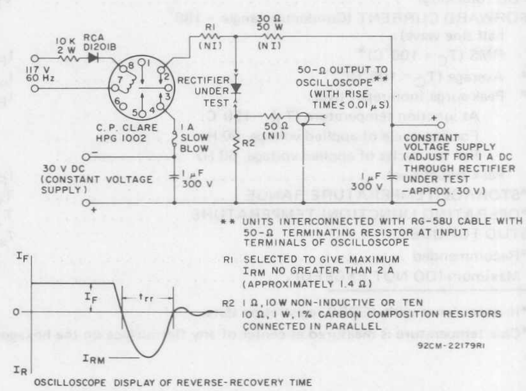
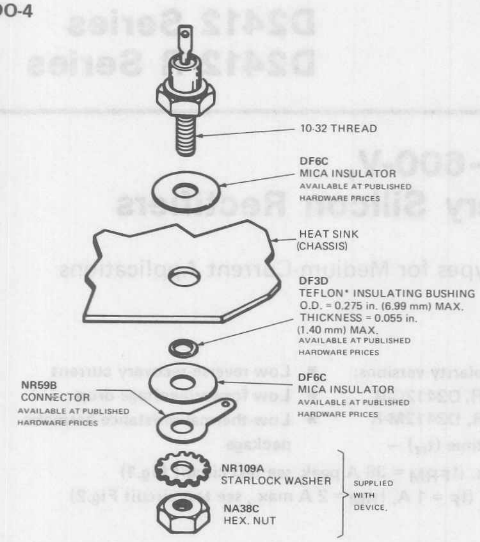


Fig. 2 — Test circuit (pulsed dc) for measurement of reverse-recovery time.

DO-4



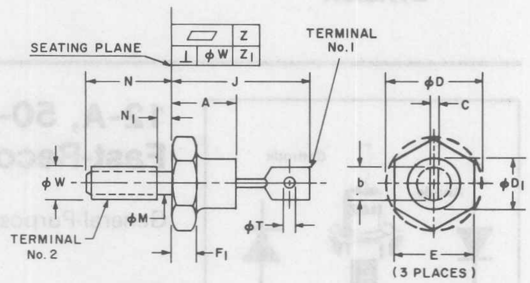
* REGISTERED TRADEMARK OF E. I. DUPONT DE NEMOUR & CO.

92CS-22573

In the United Kingdom, Europe, Middle East, and Africa, mounting-hardware policies may differ; check the availability of all items shown with your RCA sales representative or supplier.

Fig. 3 — Suggested mounting hardware.

DIMENSIONAL OUTLINE JEDEC DO-4



SYMBOL	INCHES MIN.	INCHES MAX.	MILLIMETERS MIN.	MILLIMETERS MAX.	NOTES
A	–	0.405	–	10.28	
b	–	0.250	–	6.35	
c	0.020	0.065	0.51	1.65	
ϕD	–	0.505	–	12.82	
ϕD_1	0.265	0.424	6.74	10.76	
E	0.423	0.438	10.75	11.12	
F_1	0.075	0.175	1.91	4.44	
J	0.600	0.800	15.24	20.32	
ϕM	0.163	0.189	4.15	4.80	
N	0.422	0.453	10.72	11.50	
N_1	–	0.078	–	1.98	
ϕT	0.060	0.095	1.53	2.41	
ϕW	10-32 UNF-2A		10-32 UNF-2A		1
Z	–	0.002	–	0.050	
Z_1	–	0.006	–	0.152	

NOTE:

1: ϕW is pitch diameter of coated threads. REF: Screw Thread Standards for Federal Services, Handbook H 28 Part I. Recommended torque: 15 inch-pounds.

92CS-20472

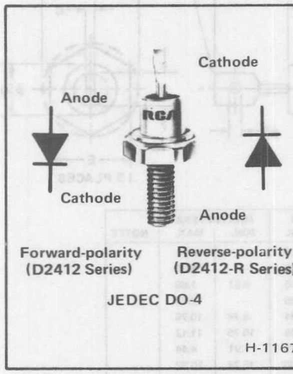
TERMINAL CONNECTIONS

Forward Polarity (1N3879 – 1N3883)	Reverse Polarity (1N3879R) – 1N3883R)
No. 1 (Lug) – Anode	No. 1 (Lug) – Cathode
No. 2 (Stud) – Cathode	No. 2 (Stud) – Anode

RCA
Solid State
Division

Rectifiers

D2412 Series
D2412-R Series



12-A, 50-to-600-V, Fast-Recovery Silicon Rectifiers

General-Purpose Types for Medium-Current Applications

Features:

- **Available in reverse-polarity versions: D2412A-R, D2412B-R, D2412C-R, D2412D-R, D2412F-R, D2412M-R**
- **Fast reverse-recovery time (t_{rr}) —**
  0.35 μs max. (I_{FRM} = 38 A peak, see test circuit Fig.1)
  0.2 μs max. (I_F = 1 A, I_{RM} = 2 A max., see test circuit Fig.2)
- **Low reverse-recovery current**
- **Low forward-voltage drop**
- **Low-thermal-resistance hermetic package**

RCA D2412 series and D2412-R series are diffused-junction silicon rectifiers in a stud-type hermetic package. These devices differ only in their voltage ratings.

All types feature fast reverse-recovery time, with "soft" recovery characteristics that reduce the generation of RFI and voltage transients.

These devices are intended for use in high-speed inverters, choppers, high-frequency rectifiers, "free-wheeling" diode circuits, and other high-frequency applications.

MAXIMUM RATINGS, *Absolute-Maximum Values:*

		D2412F (43889)* D2412F-R (43889R)*	D2412A (43890)* D2412A-R (43890R)*	D2412B (43891)* D2412B-R (43891R)*	D2412C (43892)* D2412C-R (43892R)*	D2412D (43893)* D2412D-R (43893R)*	D2412M (43894)* D2412M-R (43894R)*	
REVERSE VOLTAGE:								
Repetitive peak	V_{RRM}	50	100	200	300	400	600	V
Non-repetitive peak	V_{RSM}	100	200	300	400	600	800	V
FORWARD CURRENT (Conduction angle = 180°, half sine wave):								
RMS (T_C = 100°C)●	$I_{F(RMS)}$	18						A
Average (T_C = 100°C)●	I_o	12						A
Peak-surge (non-repetitive):	I_{FSM}							
At junction temperature (T_J) = 150°C:								
For one-half cycle of applied voltage, 60 Hz (8.3 ms)		250						A
For other durations		See Fig.3						
Peak (repetitive)	I_{FRM}	50						A
STORAGE-TEMPERATURE RANGE		−40 to 165						°C
OPERATING (JUNCTION) TEMPERATURE		150						°C
STUD TORQUE:								
Recommended		15						in-lb
Maximum (DO NOT EXCEED)		25						in-lb

* Number in parentheses is a former RCA type number.

● Case temperature is measured at center of any flat surface on the hexagonal head of the mounting stud.

ELECTRICAL CHARACTERISTICS

CHARACTERISTIC	SYMBOL	LIMITS ALL TYPES MIN.	LIMITS ALL TYPES MAX.	UNITS
Reverse Current:				
Static				
For V_{RRM} = max. rated value, I_F = 0, T_C = 25°C	I_{RM}	–	100	μA
T_C = 100°C		–	4	mA
Instantaneous Forward Voltage Drop:				
At i_F = 12 A, T_J = 25°C	v_F	–	1.4	V
Reverse Recovery Time:				
For circuit shown in Fig. 1, at I_{FM} = 38 A, $-di_F/dt$ = 25 A/μs, pulse duration = 4.5 μs, T_C = 25°C	t_{rr}	–	0.35	μs
For circuit shown in Fig. 2, at I_{FM} = 1 A, I_{RM} = 2 A max., T_C = 25°C		–	0.2	
Thermal Resistance (Junction-to-Case)	$R_{\theta JC}$	–	1.5	°C/W

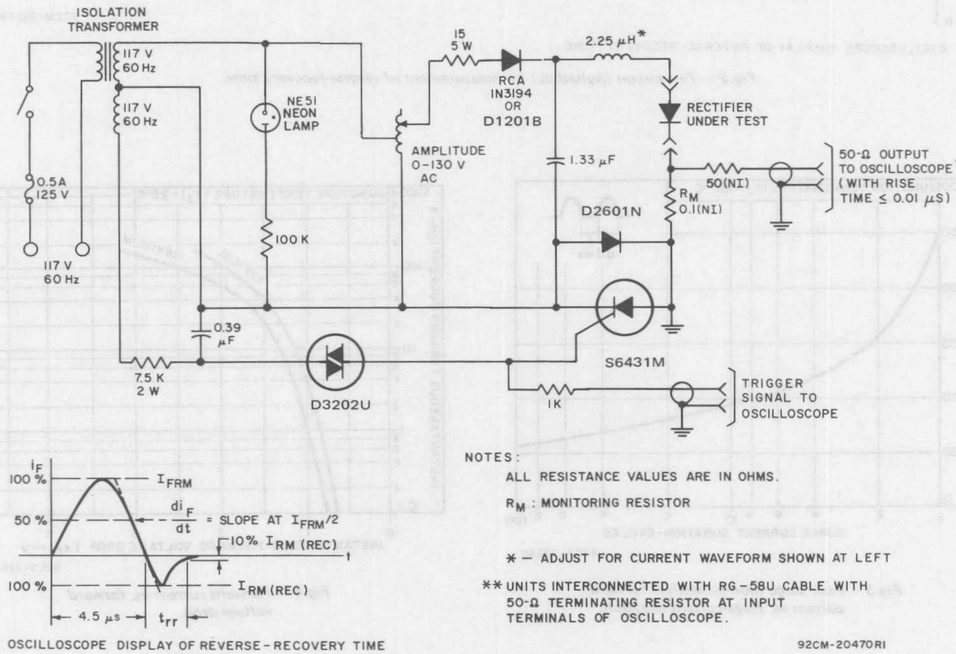


Fig.1 – Test circuit (pulsed sine wave) for measurement of reverse-recovery time.

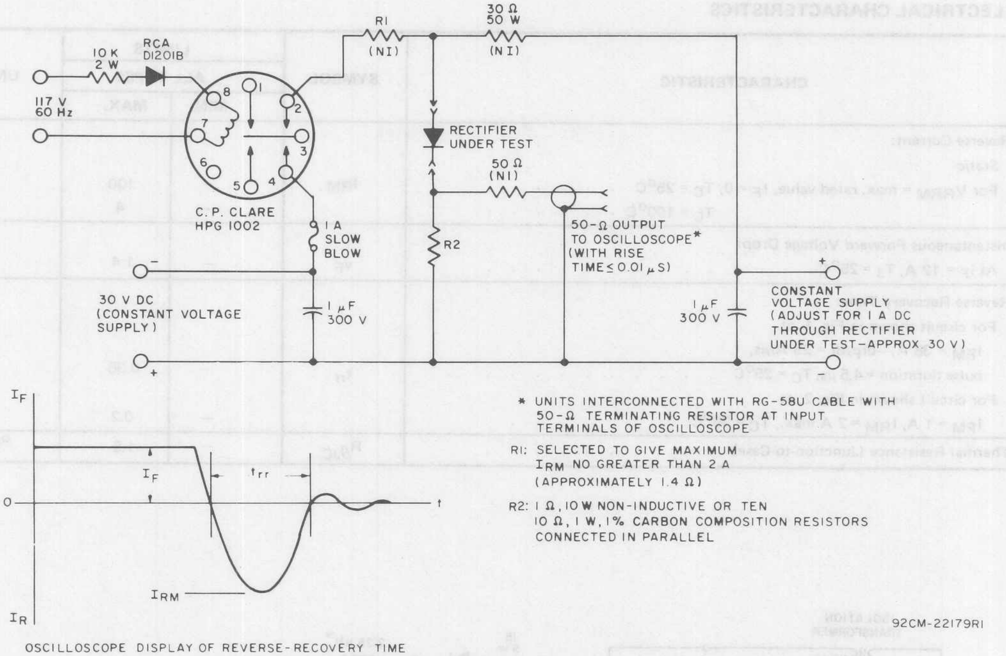


Fig.2 – Test circuit (pulsed dc) for measurement of reverse-recovery time.

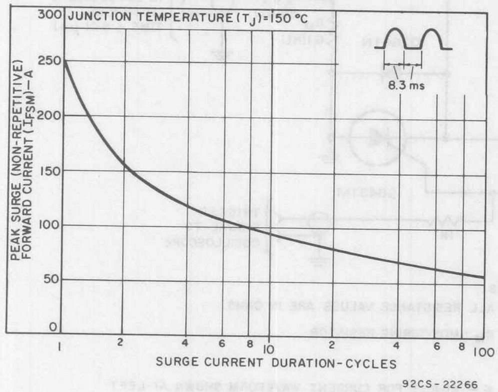


Fig.3 – Peak surge (non-repetitive) forward current vs. surge-current duration.

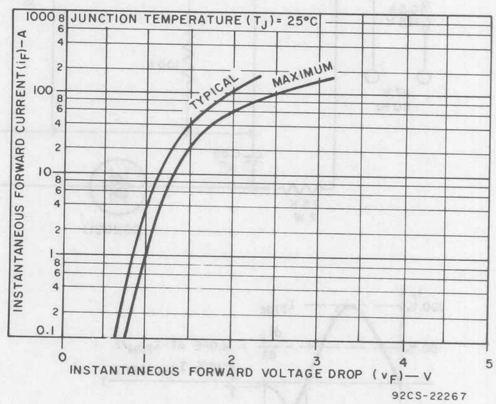


Fig.4 – Forward current vs. forward voltage drop.

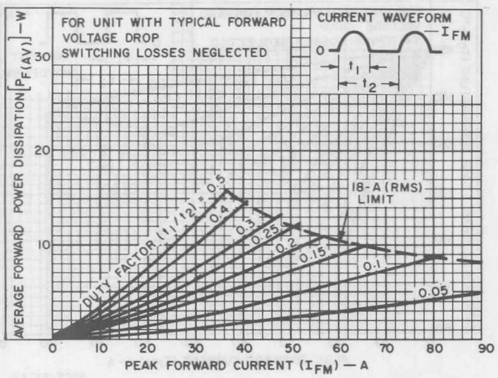


Fig.5 — Average forward power dissipation as a function of peak current and duty factor for units with typical forward voltage drop.

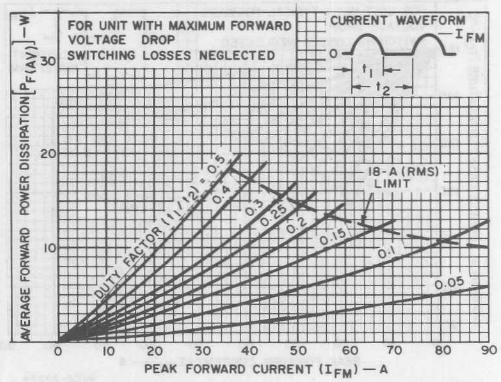


Fig.6 — Average forward power dissipation as a function of peak current and duty factor for units with maximum forward voltage drop.

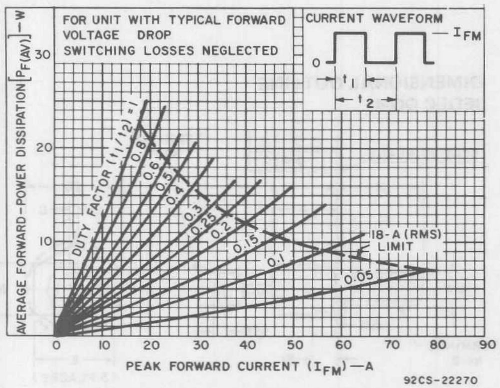


Fig.7 — Average forward power dissipation as a function of peak current and duty factor for units with typical forward voltage drop.

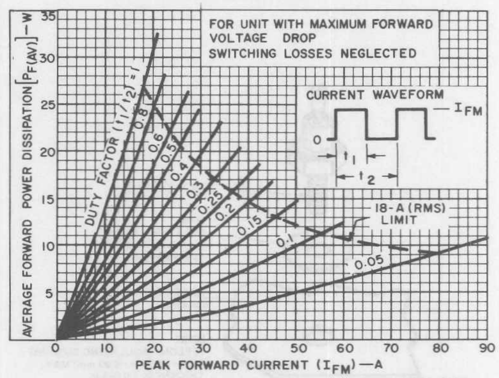


Fig.8 — Average forward power dissipation as a function of peak current and duty factor for units with maximum forward voltage drop.

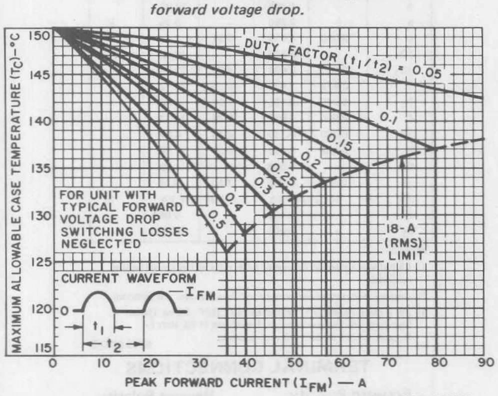


Fig.9 — Maximum allowable case temperature as a function of peak current and duty factor for units with typical forward voltage drop.

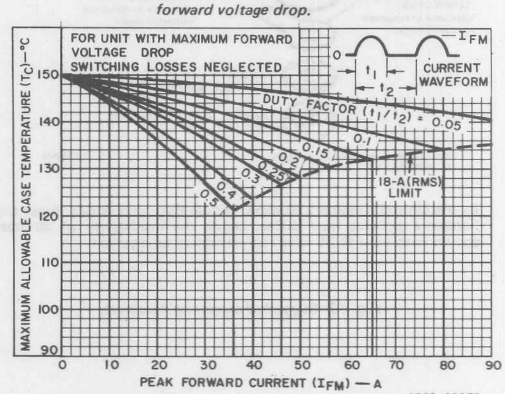


Fig.10 — Maximum allowable case temperature as a function of peak current and duty factor for units with maximum forward voltage drop.

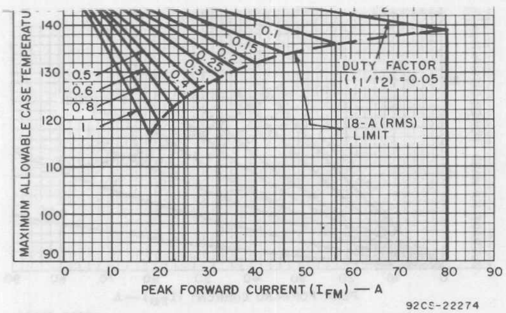


Fig.11 – Maximum allowable case temperature as a function of peak current and duty factor for units with typical forward voltage drop.

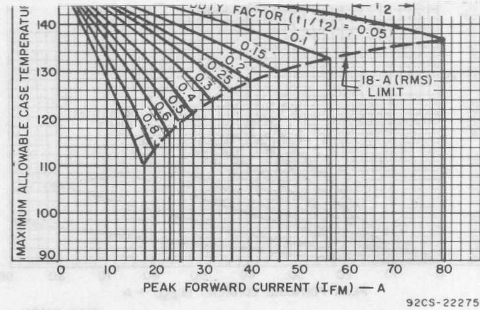
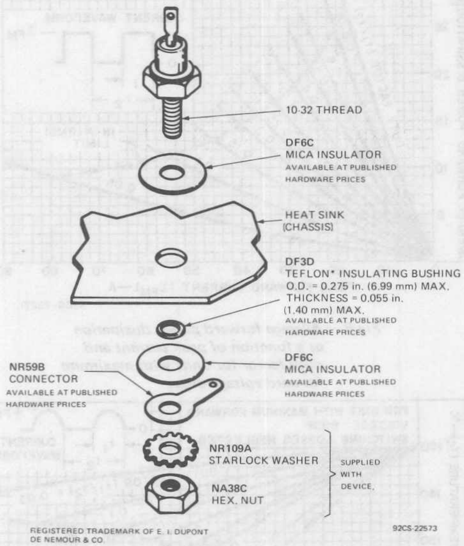


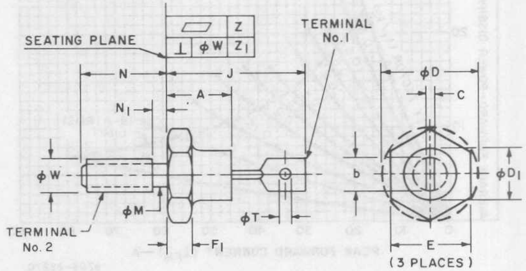
Fig.12 – Maximum allowable case temperature as a function of peak current and duty factor for units with maximum forward voltage drop.



In the United Kingdom, Europe, Middle East, and Africa, mounting-hardware policies may differ; check the availability of all items shown with your RCA sales representative or supplier.

Fig. 13—Suggested mounting hardware.

DIMENSIONAL OUTLINE JEDEC DO-4



SYMBOL	INCHES MIN.	INCHES MAX.	MILLIMETERS MIN.	MILLIMETERS MAX.	NOTES
A	–	0.405	–	10.28	
b	–	0.250	–	6.35	2
c	0.020	0.065	0.51	1.65	
φD	–	0.505	–	12.82	
ϕD_1	0.265	0.424	6.74	10.76	
E	0.423	0.438	10.75	11.12	
F_1	0.075	0.175	1.91	4.44	1
J	0.600	0.800	15.24	20.32	
φM	0.163	0.189	4.15	4.80	
N	0.422	0.453	10.72	11.50	
N_1	–	0.078	–	1.98	
φT	0.060	0.095	1.53	2.41	
φW	10-32 UNF-2A		10-32 UNF-2A		3
Z	–	0.002	–	0.050	
Z_1	–	0.006	–	0.152	

NOTES:

1: Chamfer or undercut on one or both sides of hexagonal base is optional.

2: Angular orientation and contour of Terminal No. 1 is optional.

3: φW is pitch diameter of coated threads. REF: Screw Thread Standards for Federal Services, Handbook H 28 Part I. Recommended torque: 15 inch-pounds.

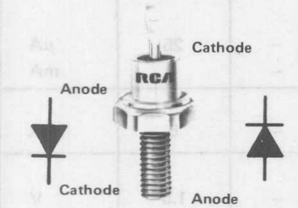
92CS-20472

TERMINAL CONNECTIONS

Forward Polarity (D2412 Series)	Reverse Polarity, (D2412-R Series)
No.1 (Lug) – Anode	No.1 (Lug) – Cathode
No.2 (Stud) – Cathode	No.2 (Stud) – Anode

RCA
Solid State Division

Rectifiers
1N3889–1N3893
1N3889R–1N3893R



Forward-polarity (1N3889-1N3893) Reverse-polarity (1N3889R-1N3893R)

JEDEC DO-4

H-1167

12-A, 50-to-400-V, Fast-Recovery Silicon Rectifiers

General-Purpose Types for High-Current Applications

Features:

- **Available in reverse-polarity versions: 1N3889R, 1N3890R, 1N3891R, 1N3892R, 1N3893R**
- **Fast reverse-recovery time (t_{rr}) — 200 ns max. (I_F = 1 A, I_{RM} = 2 A max., see test circuit Fig. 2)**
- **Low reverse-recovery current**
- **Low forward-voltage drop**
- **Low-thermal-resistance hermetic package**

For data on other RCA fast recovery rectifiers, refer to the following RCA data bulletins:
6-A File No. 663 (D2406 Series)
12-A File No. 664 (D2412 Series)
20-A File No. 665 (D2520 Series)
40-A File No. 580 (D2540 Series)

RCA types 1N3889 – 1N3893 and 1N3889R – 1N3893R are diffused-junction silicon rectifiers in a stud-type hermetic package. These devices differ only in their voltage ratings.

All types feature fast reverse-recovery time of 200 ns max. These devices are intended for use in high-speed inverters choppers, high-frequency rectifiers, "free-wheeling" diode circuits, and other high-frequency applications

MAXIMUM RATINGS, *Absolute-Maximum Values:*

		1N3889 1N3889R	1N3890 1N3890R	1N3891 1N3891R	1N3892 1N3892R	1N3893 1N3893R	
REVERSE VOLTAGE:							
*Repetitive peak	V_{RRM}	50	100	200	300	400	V
Non-repetitive peak	V_{RSM}	75	200	300	400	500	V
*DC (Blocking)	V_R	50	100	200	300	400	V
FORWARD CURRENT (Conduction angle = 180°, half sine wave):							
RMS (T_C = 100°C)▲	$I_{F(RMS)}$	18					A
* Average (T_C = 100°C)▲	I_o	12					A
* Peak-surge (non-repetitive):	I_{FSM}						
At junction temperature (T_J) = 150°C:							
For one cycle of applied voltage, 60 Hz		150					A
For ten cycles of applied voltage, 60 Hz		70					A
Peak (repetitive)	I_{FRM}	50					A
*STORAGE-TEMPERATURE RANGE	T_{stg}	−65 to 175					°C
*OPERATING (JUNCTION) TEMPERATURE	T_J	−65 to 150					°C
STUD TORQUE:	τ_s						
*Recommended		15					in-lb
Maximum (DO NOT EXCEED)		25					in-lb

*In accordance with JEDEC registration data.
▲Case temperature is measured at center of any flat surface on the hexagonal head of the mounting stud.

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ELECTRICAL CHARACTERISTICS

CHARACTERISTIC	SYMBOL	LIMITS ALL TYPES MIN.	LIMITS ALL TYPES MAX.	UNITS
* Reverse Current:				
Static				
For V_{RRM} = max. rated value, $I_F = 0$, $T_C = 25^\circ C$	I_{RM}	–	25	μA
$T_C = 100^\circ C$		–	3	mA
Dynamic				
For single phase full cycle average, I_o = 12 A, $T_C = 100^\circ C$	$I_{R(AV)}$	–	5	mA
* Instantaneous Forward Voltage Drop:				
At i_F = 12 A, V_{RRM} = rated value, $T_J = 100^\circ C$	$v_{F(PK)}$	–	1.5	V
At i_F = 12 A, $T_J = 25^\circ C$	v_F	–	1.4	V
* Reverse Recovery Time: For circuit shown in Fig. 2, at I_{FM} = 1 A, I_{RM} = 2 A max., $T_C = 25^\circ C$	t_{rr}	–	200	ns
Thermal Resistance (Junction-to-Case)	$R_{\theta JC}$	–	1.5	°C/W

*In accordance with JEDEC registration data.

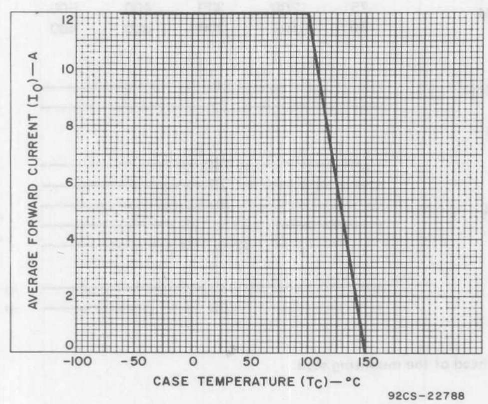


Fig. 1 – Average forward current vs. case temperature.

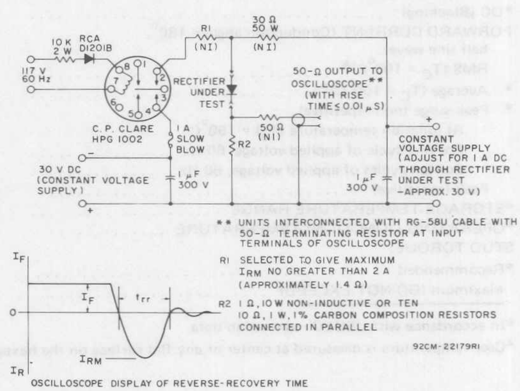
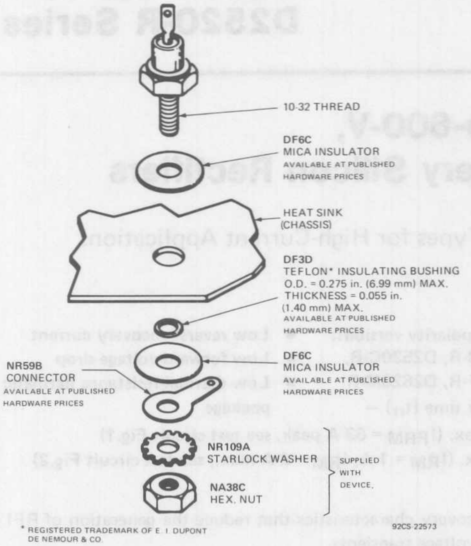


Fig.2 – Test circuit (pulsed dc) for measurement of reverse-recovery time.

DO-4

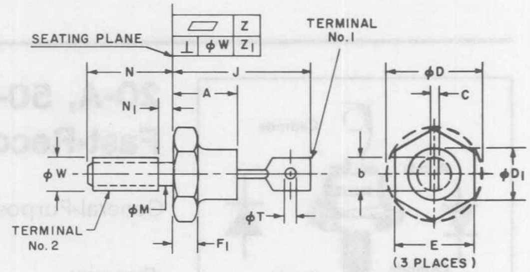


* REGISTERED TRADEMARK OF E. I. DUPONT DE NEMOUR & CO.

In the United Kingdom, Europe, Middle East, and Africa, mounting-hardware policies may differ; check the availability of all items shown with your RCA sales representative or supplier.

Fig. 3 – Suggested mounting hardware.

DIMENSIONAL OUTLINE
JEDEC DO-4



SYMBOL	INCHES MIN.	INCHES MAX.	MILLIMETERS MIN.	MILLIMETERS MAX.	NOTES
A	–	0.405	–	10.28	
b	–	0.250	–	6.35	
c	0.020	0.065	0.51	1.65	
ϕD	–	0.505	–	12.82	
ϕD_1	0.265	0.424	6.74	10.76	
E	0.423	0.438	10.75	11.12	
F_1	0.075	0.175	1.91	4.44	
J	0.600	0.800	15.24	20.32	
ϕM	0.163	0.189	4.15	4.80	
N	0.422	0.453	10.72	11.50	
N_1	–	0.078	–	1.98	
ϕT	0.060	0.095	1.53	2.41	
ϕW	10-32 UNF-2A		10-32 UNF-2A		1
Z	–	0.002	–	0.050	
Z_1	–	0.006	–	0.152	

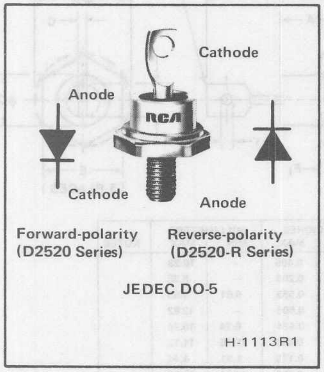
NOTE:

1: ϕW is pitch diameter of coated threads. REF: Screw Thread Standards for Federal Services, Handbook H 28 Part I. Recommended torque: 15 inch-pounds.

92CS-20472

TERMINAL CONNECTIONS

Forward Polarity (1N3889 – 1N3893)	Reverse Polarity (1N3889R – 1N3893R)
No. 1 (Lug) – Anode	No. 1 (Lug) – Cathode
No. 2 (Stud) – Cathode	No. 2 (Stud) – Anode



20-A, 50-to-600-V, Fast-Recovery Silicon Rectifiers

General-Purpose Types for High-Current Applications

Features:

- **Available in reverse-polarity versions: D2520A-R, D2520B-R, D2520C-R, D2520D-R, D2520F-R, D2520M-R**
- **Fast reverse-recovery time (t_{rr}) —**
  0.35 μs max. (I_{FRM} = 63 A peak, see test circuit Fig.1)
  0.2 μs max. (I_{RM} = 1 A, I_{RM} = 2 A max., see test circuit Fig.2)
- **Low reverse-recovery current**
- **Low forward-voltage drop**
- **Low-thermal-resistance hermetic package**

RCA D2520 series and D2520-R series are diffused-junction silicon rectifiers in a stud-type hermetic package. These devices differ only in their voltage ratings.

All types feature fast reverse-recovery time, with "soft" recovery characteristics that reduce the generation of RFI and voltage transients.

These devices are intended for use in high-speed inverters, choppers, high-frequency rectifiers, "free-wheeling" diode circuits, and other high-frequency applications.

MAXIMUM RATINGS, *Absolute-Maximum Values:*

		D2520F (43899)* D2520F-R (43899R)*	D2520A (43900)* D2520A-R (43900R)*	D2520B (34901)* D2520B-R (43901R)*	D2520C (43902)* D2520C-R (43902R)*	D2520D (43903)* D2520D-R (43903R)*	D2520M (43904)* D2520M-R (43904R)*	
REVERSE VOLTAGE:								
Repetitive peak	V_{RRM}	50	100	200	300	400	600	V
Non-repetitive peak	V_{RSM}	100	200	300	400	600	800	V
FORWARD CURRENT (Conduction angle = 180°, half sine wave):								
RMS (T_C = 100°C)●	$I_{F(RMS)}$				30			A
Average (T_C = 100°C)●	I_o				20			A
Peak-surge (non-repetitive):	I_{FSM}							
At junction temperature (T_J) = 150°C:								
For one-half cycle of applied voltage, 60 Hz (8.3 ms)					300			A
For other durations					See Fig.3			
Peak (repetitive)	I_{FRM}				100			A
STORAGE-TEMPERATURE RANGE					−40 to 165			°C
OPERATING (JUNCTION) TEMPERATURE					150			°C
STUD TORQUE:								
Recommended					30			in-lb
Maximum (DO NOT EXCEED)					50			in-lb

* Number in parentheses is a former RCA type number
● Case temperature is measured at center of any flat surface on the hexagonal head of the mounting stud.

ELECTRICAL CHARACTERISTICS

CHARACTERISTIC	SYMBOL	LIMITS ALL TYPES MIN.	LIMITS ALL TYPES MAX.	UNITS
Reverse Current: *Static* For V_{RRM} = max. rated value, I_F = 0, T_C = 25°C	I_{RM}	–	0.05	μA
T_C = 100°C		–	6	mA
Instantaneous Forward Voltage Drop: At i_F = 20 A, T_J = 25°C	v_F	–	1.4	V
Reverse Recovery Time: For circuit shown in Fig. 1, at I_{FM} = 63 A, $-di_F/dt$ = 25 A/μs, pulse duration = 7.5 μs, T_C = 25°C	t_{rr}	–	0.35	μs
For circuit shown in Fig. 2, at I_{FM} = 1 A, I_{RM} = 2 A max., T_C = 25°C		–	0.2	
Thermal Resistance (Junction-to-Case)	$R_{\theta JC}$	–	1	°C/W

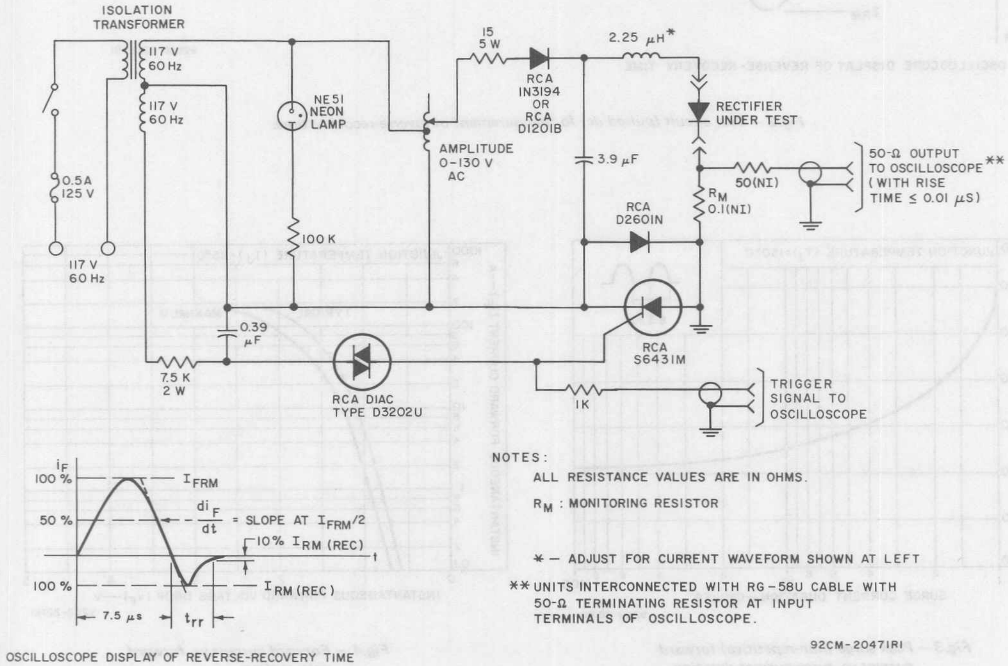


Fig.1 – Test circuit (pulsed sine wave) for measurement of reverse-recovery time.

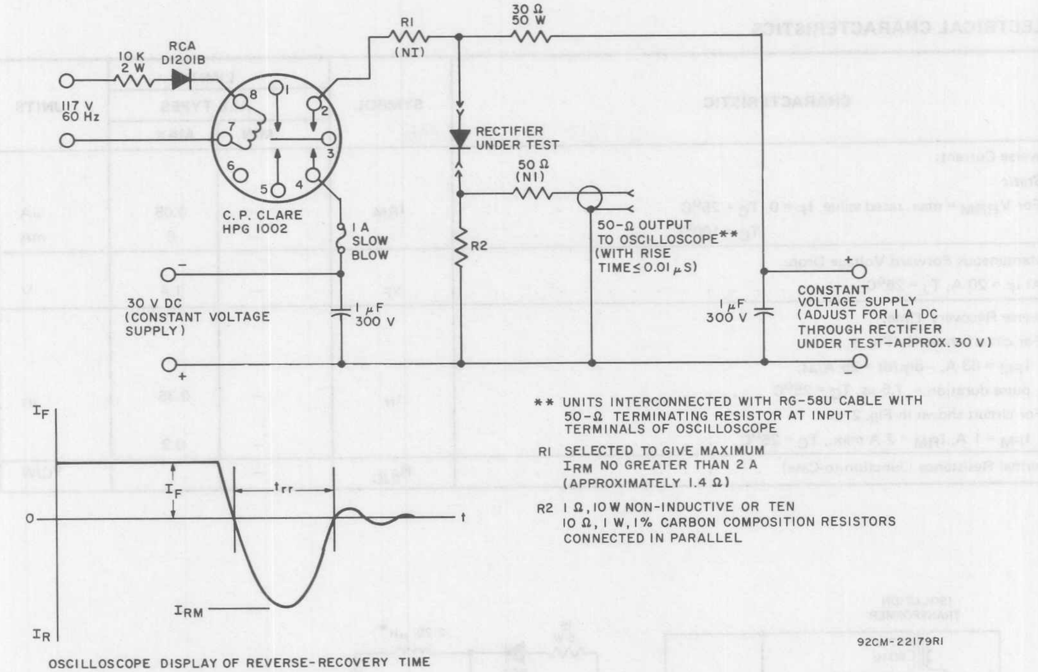


Fig.2 – Test circuit (pulsed dc) for measurement of reverse-recovery time.

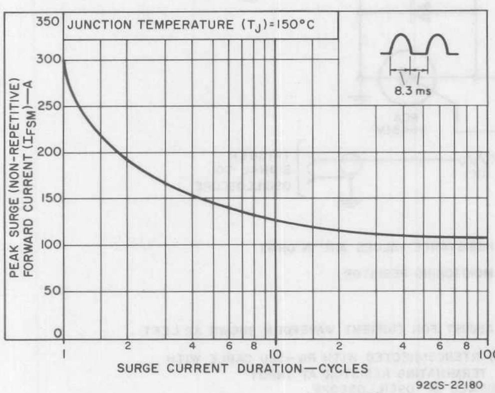


Fig.3 – Peak surge (non-repetitive) forward current vs. surge-current duration.

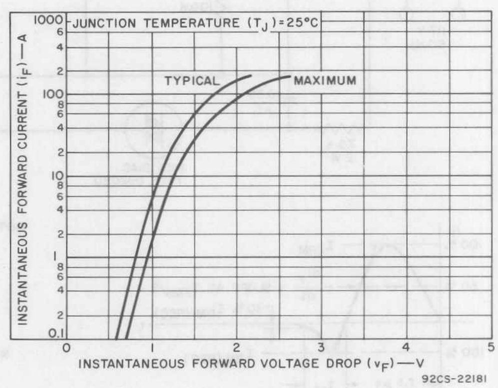


Fig.4 – Forward current vs. forward voltage drop.

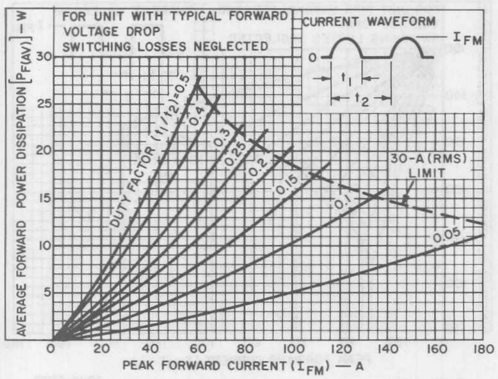


Fig.5 – Average forward power dissipation as a function of peak current and duty factor for units with typical forward voltage drop.

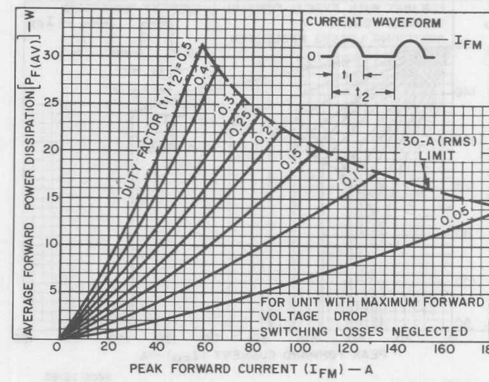


Fig.6 Average forward power dissipation as a function of peak current and duty factor for units with maximum forward voltage drop.

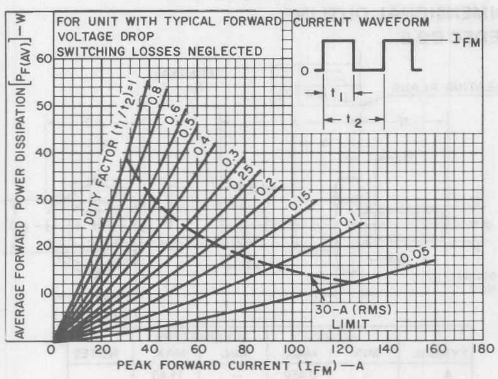


Fig.7 – Average forward power dissipation as a function of peak current and duty factor for units with typical forward voltage drop.

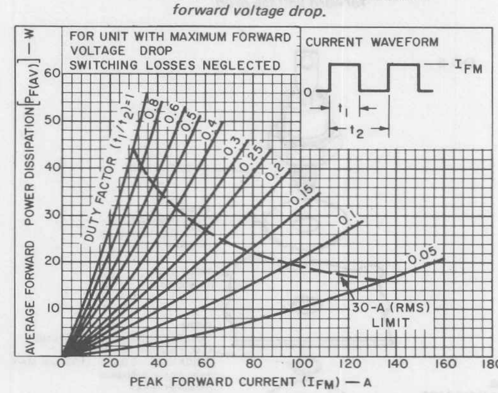


Fig.8 – Average forward power dissipation as a function of peak current and duty factor for units with maximum forward voltage drop.

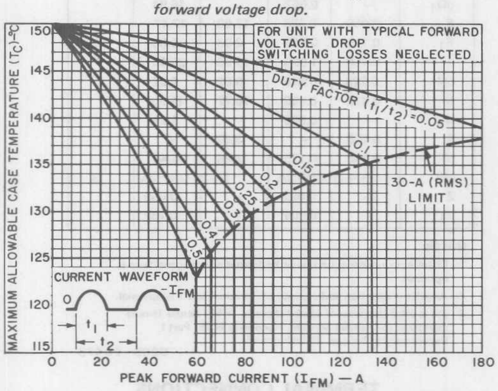


Fig.9 – Maximum allowable case temperature as a function of peak current and duty factor for units with typical forward voltage drop.

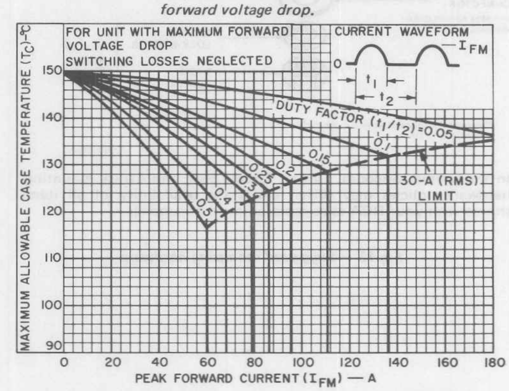


Fig.10 – Maximum allowable case temperature as a function of peak current and duty factor for units with maximum forward voltage drop.

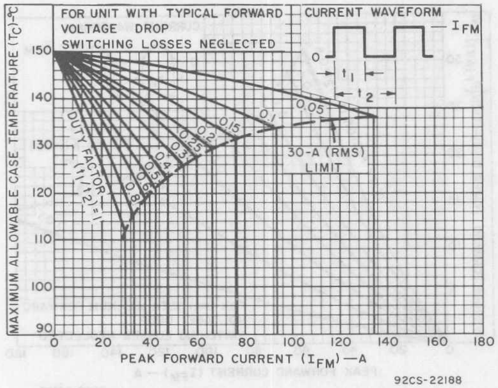


Fig.11 – Maximum allowable case temperature as a function of peak current and duty factor for units with typical forward voltage drop.

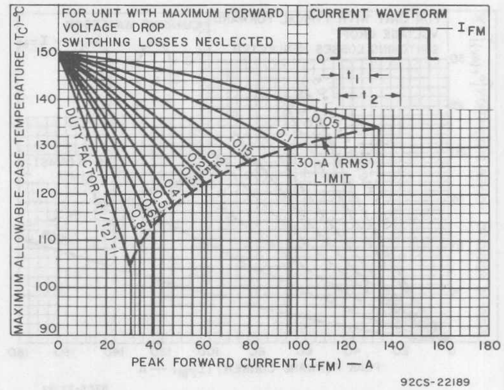
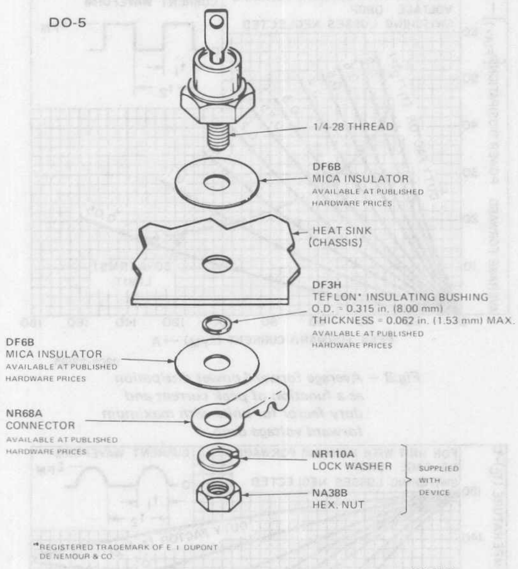


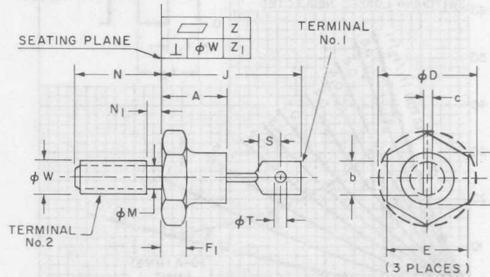
Fig.12 – Maximum allowable case temperature as a function of peak current and duty factor for units with maximum forward voltage drop.



In the United Kingdom, Europe, Middle East, and Africa, mounting-hardware policies may differ; check the availability of all items shown with your RCA sales representative or supplier.

Fig.13 – Suggested mounting hardware.

DIMENSIONAL OUTLINE JEDEC DO-5



SYMBOL	INCHES MIN.	INCHES MAX.	MILLIMETERS MIN.	MILLIMETERS MAX.	NOTES
A	–	0.450	–	11.43	
b	–	0.375	–	9.52	2
c	0.030	0.080	0.77	2.03	
ϕD	–	0.794	–	20.16	
ϕD_1	–	0.667	–	16.94	
E	0.669	0.688	17.00	17.47	
F_1	0.115	0.200	2.93	5.08	1
J	0.750	1.000	19.05	25.40	
ϕM	0.220	0.249	5.59	6.32	
N	0.422	0.453	10.72	11.50	
N_1	–	0.090	–	2.28	
S	0.156	–	3.97	–	
ϕT	0.140	0.175	3.56	4.44	
ϕW	1/4-28 UNF 2A		1/4-28 UNF 2A		3
Z	–	0.002	–	0.050	
Z_1	–	0.006	–	0.152	

NOTES:

1: Chamfer or undercut on one or both sides of hexagonal base is optional.

2: Angular orientation and contour of Terminal No. 1 is optional.

3: ϕW is pitch diameter of coated threads. REF: Screw-Thread Standards for Federal Services, Handbook H 28 Part I. Recommended torque: 30 inch-pounds.

92CS-20473

TERMINAL CONNECTIONS

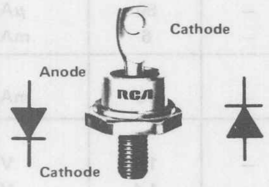
Forward Polarity (D2520 Series)	Reverse Polarity (D2520-R Series)
No.1 (Lug) – Anode	No.1 (Lug) – Cathode
No.2 (Stud) – Cathode	No.2 (Stud) – Anode

File No. 728

RCA Solid State Division

Rectifiers

1N3899–1N3903
1N3899R–1N3903R



Forward-polarity (1N3899-1N3903) Reverse-polarity (1N3899R-1N3903R)

JEDEC DO-5

H-1113R1

20-A, 50-to-400-V, Fast-Recovery Silicon Rectifiers

General-Purpose Types for High-Current Applications

Features:

- Available in reverse-polarity versions: 1N3899R, 1N3900R, 1N3901R, 1N3902R, 1N3903R
- Fast reverse-recovery time (t_{rr}) – 200 ns max. (I_{RM} = 1 A, I_{RM} = 2 A max., see test circuit Fig. 2)
- Low reverse-recovery current
- Low forward-voltage drop
- Low-thermal-resistance hermetic package

For data on other RCA fast recovery rectifiers, refer to the following RCA data bulletins:
6-A File No. 663 (D2406 Series)
12-A File No. 664 (D2412 Series)
20-A File No. 665 (D2520 Series)
40-A File No. 580 (D2540 Series)

RCA types 1N3899–1N3903 and 1N3899R–1N3903R are diffused-junction silicon rectifiers in a stud-type hermetic package. These devices differ only in their voltage ratings.

All types feature fast reverse-recovery time of 200 ns max. These devices are intended for use in high-speed inverters, choppers, high-frequency rectifiers, "free-wheeling" diode circuits, and other high-frequency applications

MAXIMUM RATINGS, *Absolute-Maximum Values:*

		1N3899 1N3899R	1N3900 1N3900R	1N3901 1N3901R	1N3902 1N3902R	1N3903 1N3903R	
REVERSE VOLTAGE:							
*Repetitive peak	V_{RRM}	50	100	200	300	400	V
Non-repetitive peak	V_{RSM}	75	200	300	400	500	V
*DC (Blocking)	V_R	50	100	200	300	400	V
FORWARD CURRENT (Conduction angle = 180°, half sine wave):							
RMS (T_C = 100°C)▲	$I_{F(RMS)}$			30			A
* Average (T_C = 100°C)▲	I_o			20			A
* Peak-surge (non-repetitive):	I_{FSM}						
At junction temperature (T_J) = 150°C:							
For one cycle of applied voltage, 60 Hz				225			A
For ten cycles of applied voltage, 60 Hz				120			A
Peak (repetitive)	I_{FRM}			100			A
*STORAGE-TEMPERATURE RANGE	T_{stg}			–65 to 175			°C
*OPERATING (JUNCTION) TEMPERATURE	T_J			–65 to 150			°C
STUD TORQUE:	T_s						
*Recommended				30			in-lb
Maximum (DO NOT EXCEED)				50			in-lb

*In accordance with JEDEC registration data.

▲Case temperature is measured at center of any flat surface on the hexagonal head of the mounting stud.

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		MIN.	MAX.	
* Reverse Current:				
Static				
For V_{RRM} = max. rated value, $I_F = 0$, $T_C = 25^\circ C$	I_{RM}	–	50	μA
$T_C = 100^\circ C$		–	6	mA
Dynamic				
For single phase full cycle average, $I_o = 20$ A, $T_C = 100^\circ C$	$I_{R(AV)}$	–	10	mA
* Instantaneous Forward Voltage Drop:				
At $i_F = 20$ A, V_{RRM} = rated value, $T_J = 100^\circ C$	$v_{F(PK)}$	–	1.5	V
At $i_F = 20$ A, $T_J = 25^\circ C$	v_F	–	1.4	V
* Reverse Recovery Time:				
For circuit shown in Fig. 2, at				
$I_{FM} = 1$ A, $I_{RM} = 2$ A max., $T_C = 25^\circ C$	t_{rr}	–	200	ns
Thermal Resistance (Junction-to-Case)	$R_{\theta JC}$	–	1.5	°C/W

*In accordance with JEDEC registration data.

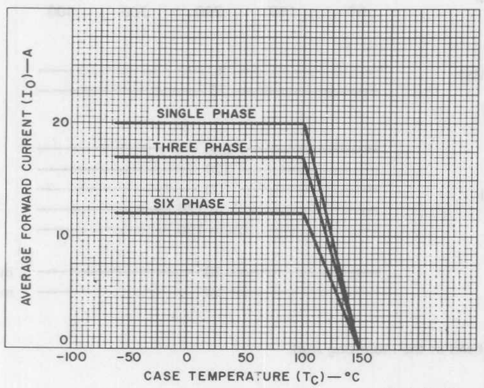


Fig. 1 – Average forward current vs. case temperature.

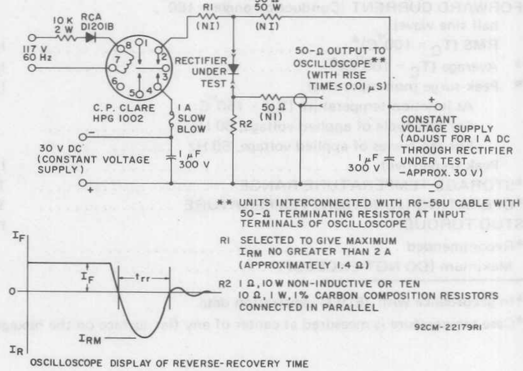
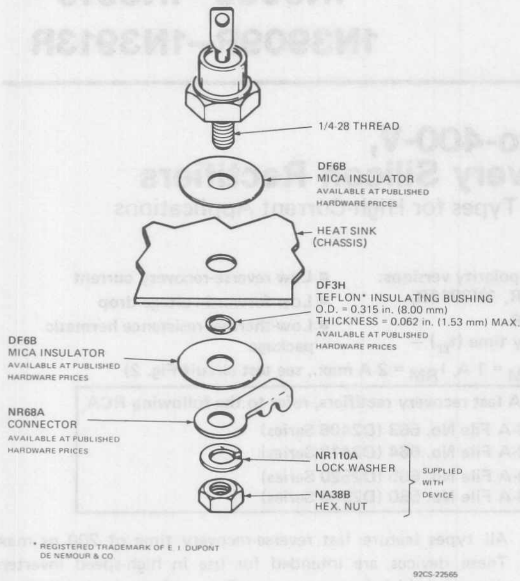


Fig. 2 Test circuit (pulsed dc) for measurement of reverse-recovery time.

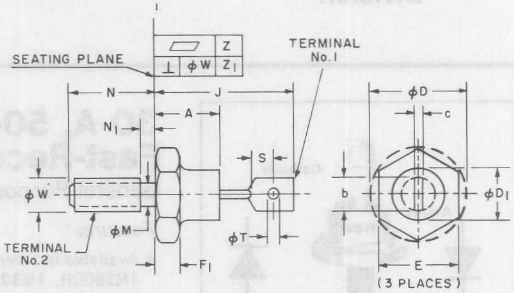
DO-5



In the United Kingdom, Europe, Middle East, and Africa, mounting-hardware policies may differ; check the availability of all items shown with your RCA sales representative or supplier.

Fig. 3 – Suggested mounting hardware.

DIMENSIONAL OUTLINE
JEDEC DO-5



SYMBOL	INCHES MIN.	INCHES MAX.	MILLIMETERS MIN.	MILLIMETERS MAX.	NOTES
A	–	0.450	–	11.43	
b	–	0.375	–	9.52	
c	0.030	0.080	0.77	2.03	
ϕD	–	0.794	–	20.16	
ϕD_1	–	0.667	–	16.94	
E	0.669	0.688	17.00	17.47	
F_1	0.115	0.200	2.93	5.08	
J	0.750	1.000	19.05	25.40	
ϕM	0.220	0.249	5.59	6.32	
N	0.422	0.453	10.72	11.50	
N_1	–	0.090	–	2.28	
S	0.156	–	3.97	–	
ϕT	0.140	0.175	3.56	4.44	
ϕW	1/4-28 UNF 2A		1/4-28 UNF 2A		1
Z	–	0.002	–	0.050	
Z_1	–	0.006	–	0.152	

NOTE

1: ϕW is pitch diameter of coated threads. REF: Screw-Thread Standards for Federal Services, Handbook H 28 Part I. Recommended torque: 30 inch-pounds.

92CS-20473R1

TERMINAL CONNECTIONS

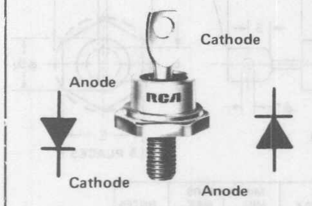
Forward Polarity (1N3899–1N3903)	Reverse Polarity (1N3899R – 1N3903R)
No. 1 (Lug) – Anode	No. 1 (Lug) – Cathode
No. 2 (Stud) – Cathode	No. 2 (Stud – Anode

RCA

Solid State Division

Rectifiers

1N3909—1N3913
1N3909R—1N3913R



30-A, 50-to-400-V, Fast-Recovery Silicon Rectifiers

General-Purpose Types for High-Current Applications

Features:

- **Available in reverse-polarity versions: 1N3909R, 1N3910R, 1N3911R, 1N3912R, 1N3913R**
- **Fast reverse-recovery time (t_{rr}) — 200 ns max. (I_{RM} = 1 A, I_{RM} = 2 A max., see test circuit Fig. 2)**
- **Low reverse-recovery current**
- **Low forward-voltage drop**
- **Low-thermal-resistance hermetic package**

For data on other RCA fast recovery rectifiers, refer to the following RCA data bulletins:
6-A File No. 663 (D2406 Series)
12-A File No. 664 (D2412 Series)
20-A File No. 665 (D2520 Series)
40-A File No. 580 (D2540 Series)

RCA types 1N3909 — 1N3913 and 1N3909R — 1N3913R are diffused-junction silicon rectifiers in a stud-type hermetic package. These devices differ only in their voltage ratings.

All types feature fast reverse-recovery time of 200 ns max. These devices are intended for use in high-speed inverters, choppers, high-frequency rectifiers, "free-wheeling" diode circuits, and other high-frequency applications

MAXIMUM RATINGS, *Absolute-Maximum Values:*

		1N3909 1N3909R	1N3910 1N3910R	1N3911 1N3911R	1N3912 1N3912R	1N3913 1N3913R	
REVERSE VOLTAGE:							
*Repetitive peak	V_{RRM}	50	100	200	300	400	V
Non-repetitive peak	V_{RSM}	75	200	300	400	500	V
*DC (Blocking)	V_R	50	100	200	300	400	V
FORWARD CURRENT (Conduction angle = 180°, half sine wave):							
RMS (T_C = 100°C)▲	$I_{F(RMS)}$			45			A
* Average (T_C = 100°C)▲	I_o			30			A
* Peak-surge (non-repetitive):	I_{FSM}						
At junction temperature (T_J) = 150°C:							
For one cycle of applied voltage, 60 Hz				300			A
For ten cycles of applied voltage, 60 Hz				160			A
Peak (repetitive)	I_{FRM}			125			A
*STORAGE-TEMPERATURE RANGE	T_{stg}			−65 to 175			°C
*OPERATING (JUNCTION) TEMPERATURE	T_J			−65 to 150			°C
STUD TORQUE:	τ_s						
*Recommended				30			in-lb
Maximum (DO NOT EXCEED)				50			in-lb

*In accordance with JEDEC registration data.

▲Case temperature is measured at center of any flat surface on the hexagonal head of the mounting stud.

ELECTRICAL CHARACTERISTICS

CHARACTERISTIC	SYMBOL	LIMITS ALL TYPES MIN.	LIMITS ALL TYPES MAX.	UNITS
* Reverse Current:				
Static				
For V_{RRM} = max. rated value, I_F = 0, T_C = 25°C	I_{RM}	–	80	μA
T_C = 100°C		–	10	mA
Dynamic				
For single phase full cycle average, I_O = 30 A, T_C = 100°C	$I_{R(AV)}$	–	15	mA
* Instantaneous Forward Voltage Drop:				
At i_F = 30 A, V_{RRM} = rated value, T_J = 100°C	$v_{F(PK)}$	–	1.5	V
At i_F = 30 A, T_J = 25°C	v_F	–	1.4	V
* Reverse Recovery Time: For circuit shown in Fig. 2, at I_{FM} = 1 A, I_{RM} = 2 A max., T_C = 25°C	t_{rr}	–	200	ns
Thermal Resistance (Junction-to-Case)	$R_{\theta JC}$	–	1	°C/W

*In accordance with JEDEC registration data.

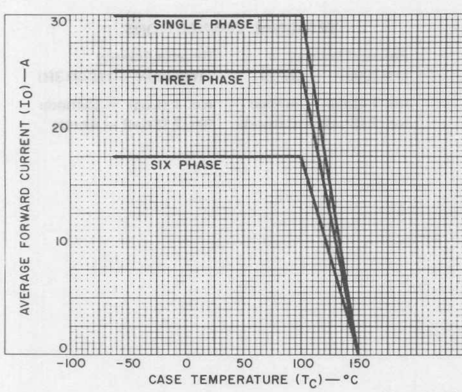


Fig. 1 — Average forward current vs. case temperature.

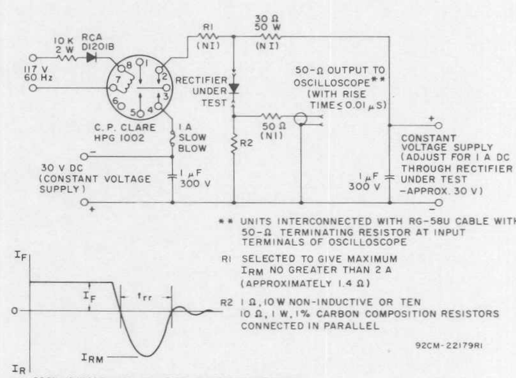
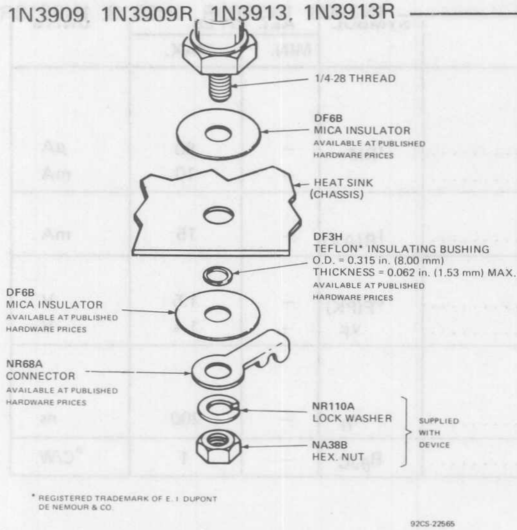
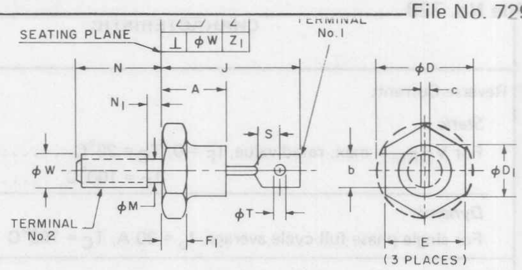


Fig. 2 — Test circuit (pulsed dc) for measurement of reverse-recovery time.



In the United Kingdom, Europe, Middle East, and Africa, mounting-hardware policies may differ; check the availability of all items shown with your RCA sales representative or supplier.

Fig. 3 – Suggested mounting hardware.



SYMBOL	INCHES MIN.	INCHES MAX.	MILLIMETERS MIN.	MILLIMETERS MAX.	NOTES
A	–	0.450	–	11.43	
b	–	0.375	–	9.52	
c	0.030	0.080	0.77	2.03	
φD	–	0.794	–	20.16	
φD_1	–	0.667	–	16.94	
E	0.669	0.688	17.00	17.47	
F_1	0.115	0.200	2.93	5.08	
J	0.750	1.000	19.05	25.40	
φM	0.220	0.249	5.59	6.32	
N	0.422	0.453	10.72	11.50	
N_1	–	0.090	–	2.28	
S	0.156	–	3.97	–	
φT	0.140	0.175	3.56	4.44	
φW	1/4-28 UNF 2A		1/4-28 UNF 2A		1
Z	–	0.002	–	0.050	
Z_1	–	0.006	–	0.152	

NOTE
1: φW is pitch diameter of coated threads. REF: Screw-Thread Standards for Federal Services, Handbook H 28 Part I. Recommended torque: 30 inch-pounds.

92CS-20473R1

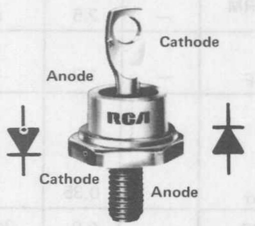
TERMINAL CONNECTIONS

Forward Polarity (1N3909 – 1N3913)	Reverse Polarity (1N3909R – 1N3913R)
No. 1 (Lug) – Anode	No. 1 (Lug) – Cathode
No. 2 (Stud) – Cathode	No. 2 (Stud) – Anode

RCA Solid State Division

Rectifiers

D2540 Series
D2540-R Series



Forward-polarity (D2540 Series)   Reverse-polarity (D2540-R Series)

JEDEC DO-5

H-1113R1

40-A, 50-to-600 V, Fast-Recovery Silicon Rectifiers

General Purpose Types for High-Current Applications

Features

- **Available in reverse-polarity versions: D2540A-R, D2540B-R, D2540D-R, D2540F-R, D2540M-R**
- **Fast reverse-recovery time — 0.35 μs max. from 125 A peak**
- **Low reverse-recovery current**
- **Low forward-voltage drop**
- **Low-thermal-resistance hermetic package**

RCA D2540 series and D2540-R series‡ inclusive, are diffused-junction-type silicon rectifiers in a stud-type hermetic package. These devices differ only in their voltage ratings.

All types feature fast reverse-recovery time (0.35 μs max. from 125 A peak) with "soft" recovery characteristics that reduce the generation of RFI and voltage transients.

These devices are intended for use in high-speed inverters, choppers, high-frequency rectifiers, "free-wheeling" diode circuits, and other high-frequency applications.

‡ Types D2540F-R, A-R, B-R, D-R, and M-R were formerly RCA Dev. Nos. TA7984-TA7987, respectively.

MAXIMUM RATINGS, *Absolute-Maximum Values:*

		D2540F (40956)* D2540F-R (40956R)*	D2540A (40957)* D2540A-R (40957R)*	D2540B (40958)* D2540B-R (40958R)*	D2540D (R0959)* D2540D-R (40959R)*	D2540M (40960)* D2540M-R (40960R)*	
REVERSE VOLTAGE							
Repetitive peak	V_{RRM}	50	100	200	400	600	V
Non-repetitive peak	V_{RSM}	100	200	300	600	800	V
FORWARD CURRENT (Conduction angle = 180°, half sine wave):							
RMS (T_C = 100°C)●	$I_{F(RMS)}$	←		60		→	A
Average (T_C = 100°C)●	I_o	←		40		→	A
Peak-surge (non-repetitive): At junction temperature (T_J) = 150°C For one-half cycle of applied voltage, 60 Hz (8.3 ms)	I_{FSM}	←		700		→	A
Peak (repetitive)	I_{FRM}	←		195		→	A
TEMPERATURE RANGE:							
Storage and Operating (Junction)		←		-40 to 150		→	°C

* Number in parentheses is a former RCA type number.
● Case temperature is measured at center of any flat surface on the heagonal head of the mounting stud.

ELECTRICAL CHARACTERISTICS

CHARACTERISTIC	SYMBOL	LIMITS ALL TYPES MIN.	LIMITS ALL TYPES MAX.	UNITS
Reverse Current: *Static* For V_{RRM} = max. rated value, I_F = 0, T_C = 25°C	I_{RM}	–	100	µA
T_C = 100°C	I_{RM}	–	2.5	mA
Instantaneous Forward Voltage Drop: At i_F = 100 A, T_J = 25°C, See Figure 2.	v_F	–	1.8	V
Reverse-Recovery Time: For circuit shown in Figure 1: At I_{FRM} = 125 A, di/dt = 25 A/µs, pulse duration = 15 µs T_C = 25°C	t_{rr}	–	0.35	µs
Thermal Resistance (Junction-to-Case)	$R_{\theta JC}$	–	0.9	°C/W

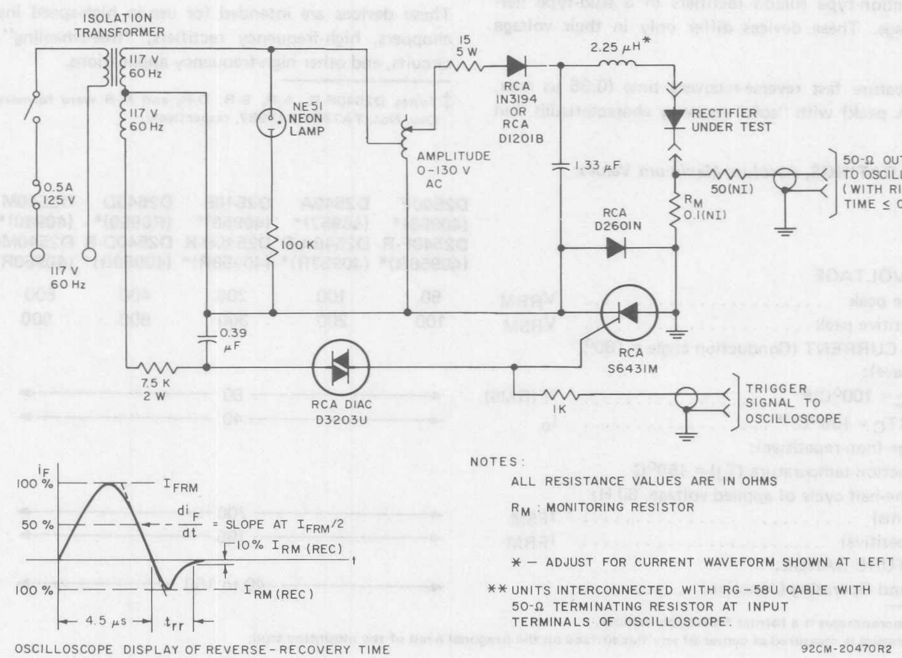


Fig.1—Oscilloscope display and test circuit for measurement of reverse-recovery time.

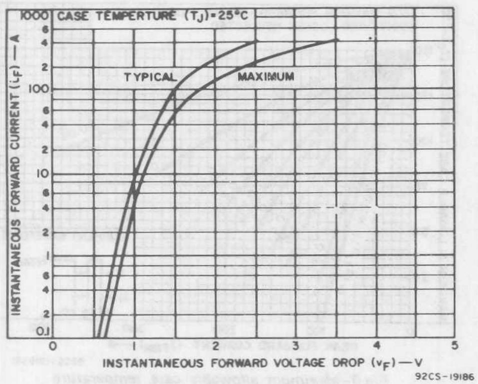


Fig.2—Forward current as a function of forward voltage drop.

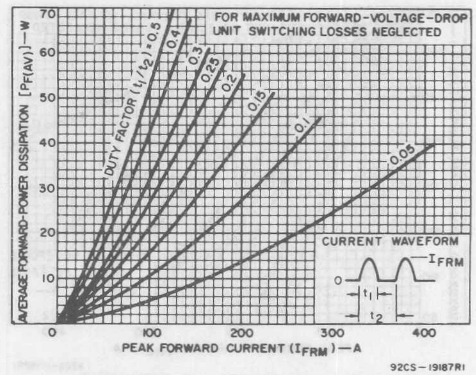


Fig.3—Average forward-power dissipation for maximum forward-voltage-drop unit.

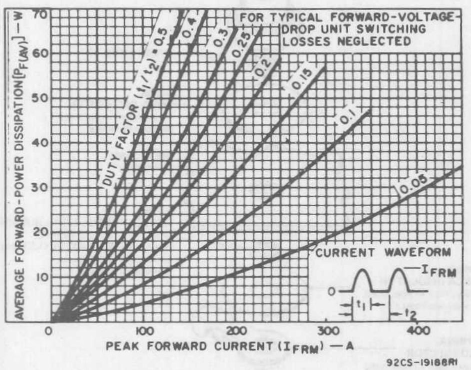


Fig.4—Average forward-power dissipation for typical forward-voltage-drop unit.

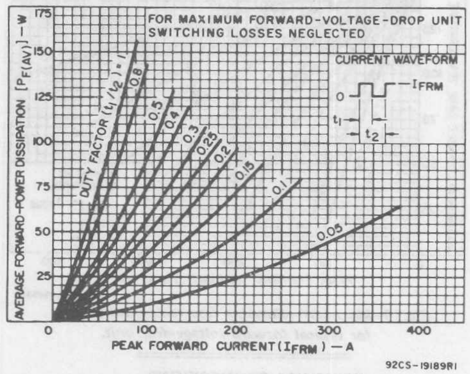


Fig.5—Average forward-power dissipation for maximum forward-voltage-drop unit.

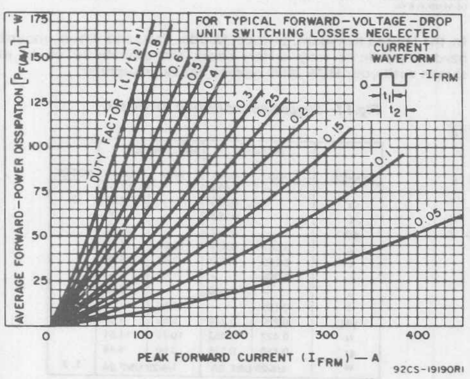


Fig.6—Average forward-power dissipation for typical forward-voltage-drop unit.

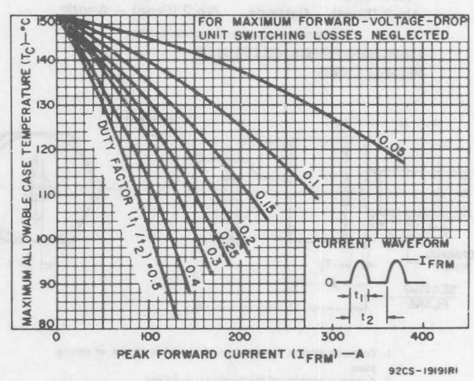


Fig.7—Maximum allowable case temperature for maximum forward-voltage-drop unit.

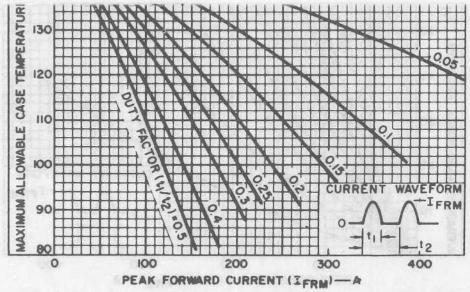


Fig.8—Maximum allowable case temperature for typical forward-voltage-drop unit.

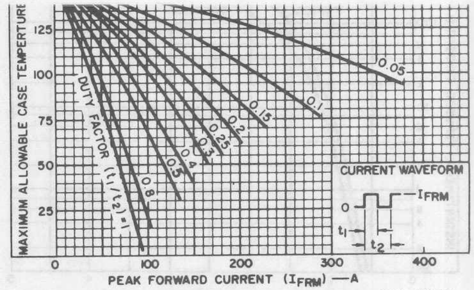


Fig.9—Maximum allowable case temperature for maximum forward-voltage-drop unit.

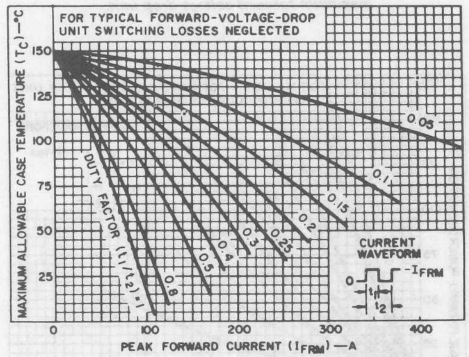
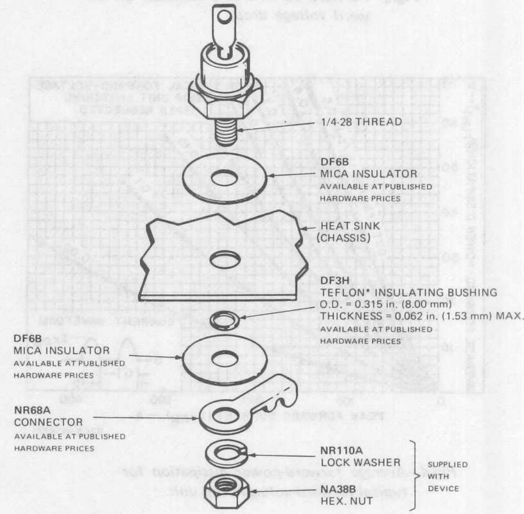


Fig.10—Maximum allowable case temperature for typical forward-voltage-drop unit.

TERMINAL CONNECTIONS

Forward Polarity (D2540 Series)	Reverse Polarity (D2540-R Series)
No.1 (Lug) — Anode	No.1 (Lug) — Cathode
No.2 (Stud) — Cathode	No.2 (Stud) — Anode



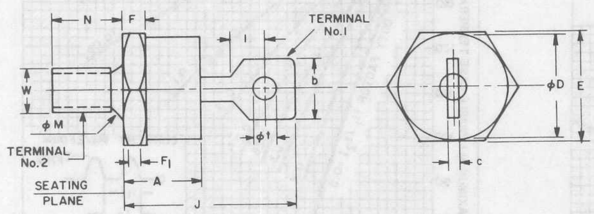
* REGISTERED TRADEMARK OF E. I. DUPONT DE NEMOUR & CO.

92CS-22565

In the United Kingdom, Europe, Middle East, and Africa, mounting-hardware policies may differ; check the availability of all items shown with your RCA sales representative or supplier.

Fig.11—Suggested mounting hardware.

DIMENSIONAL OUTLINE JEDEC DO-5



SYMBOL	INCHES MIN.	INCHES MAX.	MILLIMETERS MIN.	MILLIMETERS MAX.	NOTES
A	–	0.450	–	11.43	
b	–	0.375	–	9.53	2
c	–	0.080	–	2.03	
φD	–	0.667	–	16.94	
E	0.667	0.687	16.94	17.45	
F	0.115	0.200	2.92	5.08	
F_1	0.060	–	1.52	–	
J	–	1.000	–	25.40	
l	0.156	–	3.96	–	4
φM	0.220	0.249	5.59	6.32	1
N	0.422	0.453	10.72	11.51	
φt	0.140	0.175	3.56	4.45	
W	1/4-28 UNF 2A		1/4-28 UNF 2A		1, 3

92CS-10758R4

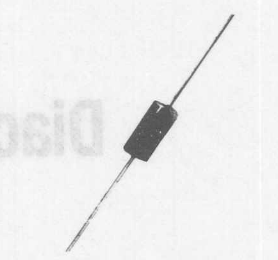
1. Complete threads to extend to within 2-1/2 threads of seating plane.
2. Angular orientation of the terminal is undefined.
3. 1/4-28 UNF-2A. Maximum pitch diameter of plated threads shall be basic pitch diameter (.2268 inch, 5.74 mm) ref. (screw thread standards for Federal Services 1957) Handbook H28 1957 Pl.
4. Minimum flat.

Diacs

RCA Solid State Division

Thyristors

D3202Y
D3202U


JEDEC DO-15

H-1783

Silicon Bidirectional Diacs

Plastic-Packaged Two-Terminal Trigger Devices for Applications in Military, Industrial, and Commercial Equipment

Features:

- **For critical triggering applications requiring narrow breakover voltage range (29-35V)—D3202Y**
- **Typical breakover voltage: $V_{(BO)}$ = 32 V**
- **Low breakover current (at breakover voltage): $I_{(BO)}$ = 25 μA max.**
- **High peak pulse current capability**
- **Breakover voltage symmetry:**
  $|+V_{(BO)}| - |-V_{(BO)}| = \pm 3$ V max.

RCA D3202Y (45411)* and D3202U (45412)* are all-diffused, three-layer, two-terminal devices in an axial-lead plastic package designed specifically for triggering thyristors. Both units exhibit bidirectional negative-resistance characteristics.

These diacs are intended for use in thyristor phase-control circuits for lamp-dimming, universal-motor speed control, and heat controls. Their small size and plastic package of high insulation resistance make these diacs especially suitable for applications in which high packing densities are employed.

*Number in parentheses is a former RCA type number.

MAXIMUM RATINGS, *Absolute-Maximum Values:*

DEVICE DISSIPATION:	
At case temperature up to 40°C	1 W
At case temperatures above 40°C	Derate 0.016 W/°C
TEMPERATURE RANGE:	
Storage	−40 to +150 °C
Operating (Junction)	−40 to +100 °C
LEAD TEMPERATURE (During Soldering)	
At distance ≥ 1/16 in. (1.59 mm) from case for 10 s max.	240 °C

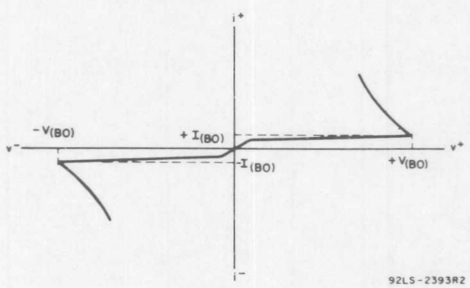


Fig. 1—Voltage-current characteristic for both types.

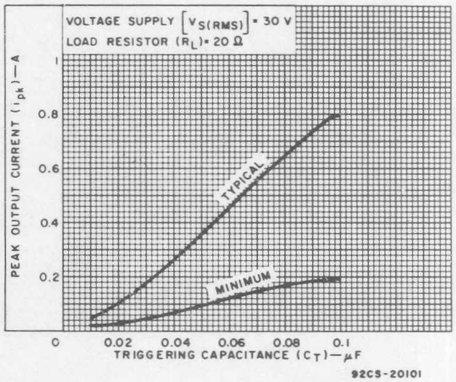


Fig.2—Peak output current vs. triggering capacitance.

ELECTRICAL CHARACTERISTICS: At Case Temperature (T_C) = 25°C

CHARACTERISTIC	SYMBOL	TEST CONDITIONS	LIMITS D3202Y MIN.	LIMITS D3202Y MAX.	LIMITS D3202U MIN.	LIMITS D3202U MAX.	UNITS
Breakover Voltage (Forward or Reverse)	$V_{(BO)}$		29	35	25	40	V
Breakover Voltage Symmetry	$\lvert +V_{(BO)} \rvert - \lvert -V_{(BO)} \rvert$		–	±3	–	±3	V
Peak Output Current (See Figs. 2, 3, & 5.)	i_{pk}	V_{SUPPLY} = 30 V_{RMS}, C_T = 0.1 μF, R_L = 20 Ω	190	–	190	–	mA
Peak Breakover Current	$I_{(BO)}$	At breakover voltage	–	25	–	25	μA
Dynamic Breakback Voltage	$\lvert \Delta V\pm \rvert$	V_{SUPPLY} = 30 V_{RMS}, C_T = 0.1 μF, R_L = 20 Ω	9	–	9	–	V
Thermal Impedance Junction-to-ambient	$I_{\theta JA}$		–	60	–	60	°C/W

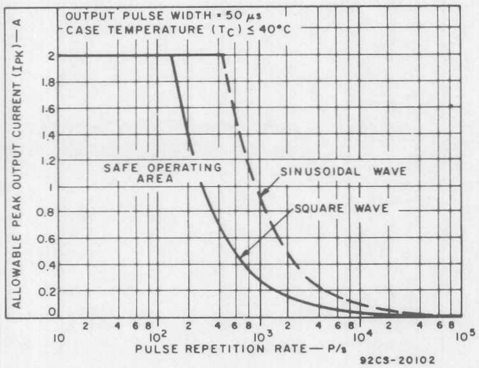


Fig.3—Peak output-current derating curves.

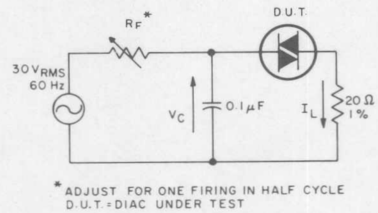


Fig.4—Circuit used to measure diac characteristics.

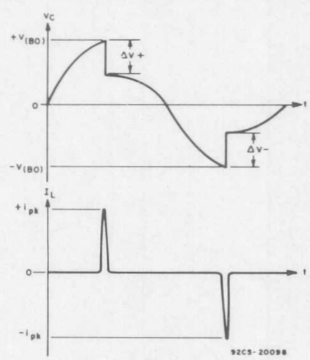
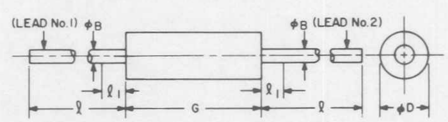


Fig.5—Test circuit waveforms (see Fig.4).

DIMENSIONAL OUTLINE FOR TYPES D3202Y & D3202U JEDEC DO-15



Lead 1 or 2 – Positive or Negative Terminal

SYMBOL	INCHES MIN.	INCHES MAX.	MILLIMETERS MIN.	MILLIMETERS MAX.
ϕb	0.027	0.035	0.686	0.889
ϕD	0.104	0.140	2.64	3.56
G	0.230	0.300	5.84	7.62
ℓ	1.000	–	25.40	–
ℓ_1*	–	0.050	–	1.27

* Within this zone the diameter may vary to allow for lead finishes and irregularities.

Application Notes

Operating Considerations for RCA Solid State Devices

Solid state devices are being designed into an increasing variety of electronic equipment because of their high standards of reliability and performance. However, it is essential that equipment designers be mindful of good engineering practices in the use of these devices to achieve the desired performance.

This Note summarizes important operating recommendations and precautions which should be followed in the interest of maintaining the high standards of performance of solid state devices.

The ratings included in RCA Solid State Devices data bulletins are based on the Absolute Maximum Rating System, which is defined by the following Industry Standard (JEDEC) statement:

Absolute-Maximum Ratings are limiting values of operating and environmental conditions applicable to any electron device of a specified type as defined by its published data, and should not be exceeded under the worst probable conditions.

The device manufacturer chooses these values to provide acceptable serviceability of the device, taking no responsibility for equipment variations, environmental variations, and the effects of changes in operating conditions due to variations in device characteristics.

The equipment manufacturer should design so that initially and throughout life no absolute-maximum value for the intended service is exceeded with any device under the worst probable operating conditions with respect to supply-voltage variation, equipment component variation, equipment control adjustment, load variation, signal variation, environmental conditions, and variations in device characteristics.

It is recommended that equipment manufacturers consult RCA whenever device applications involve unusual electrical, mechanical or environmental operating conditions.

GENERAL CONSIDERATIONS

The design flexibility provided by these devices makes possible their use in a broad range of applications and under many different operating conditions. When incorporating these devices in equipment, therefore, designers should anticipate the rare possibility of device failure and make certain that no safety hazard would result from such an occurrence.

The small size of most solid state products provides obvious advantages to the designers of electronic equipment. However, it should be recognized that these compact devices usually provide only relatively small insulation area between adjacent leads and the metal envelope. When these devices are used in moist or contaminated atmospheres, therefore, supplemental protection must be provided to prevent the development of electrical conductive paths across the relatively small insulating surfaces. For specific information on voltage creepage, the user should consult references such as the JEDEC Standard No. 7 "Suggested Standard on Thyristors," and JEDEC Standard RS282 "Standards for Silicon Rectifier Diodes and Stacks".

The metal shells of some solid state devices operate at the collector voltage and for some rectifiers and thyristors at the anode voltage. Therefore, consideration should be given to the possibility of shock hazard if the shells are to operate at voltages appreciably above or below ground potential. In general, in any application in which devices are operated at voltages which may be dangerous to personnel, suitable precautionary measures should be taken to prevent direct contact with these devices.

Devices should not be connected into or disconnected from circuits with the power on because high transient voltages may cause permanent damage to the devices.

TESTING PRECAUTIONS

In common with many electronic components, solid-state devices should be operated and tested in circuits which have reasonable values of current limiting resistance, or other forms of effective current overload protection. Failure to observe these precautions can cause excessive internal heating of the device resulting in destruction and/or possible shattering of the enclosure.

TRANSISTORS WITH FLEXIBLE LEADS

Flexible leads are usually soldered to the circuit elements. It is desirable in all soldering operations to provide some slack or an expansion elbow in each lead, to prevent excessive tension on the leads. It is important during the soldering operation to avoid excessive heat in order to prevent possible damage to the devices. Some of the heat can be absorbed if the flexible lead of the device is grasped between the case and the soldering point with a pair of pliers.

TRANSISTORS WITH MOUNTING FLANGES

The mounting flanges of JEDEC-type packages such as the TO-3 or TO-66 often serve as the collector or anode terminal. In such cases, it is essential that the mounting flange be securely fastened to the heat sink, which may be the equipment chassis. Under no circumstances, however, should the mounting flange be soldered directly to the heat sink or chassis because the heat of the soldering operation could permanently damage the device.

Such devices can be installed in commercially available sockets. Electrical connections may also be made by soldering directly to the terminal pins. Such connections may be soldered to the pins close to the pin seals provided care is taken to conduct excessive heat away from the seals; otherwise the heat of the soldering operation could crack the pin seals and damage the device.

During operation, the mounting-flange temperature is higher than the ambient temperature by an amount which depends on the heat sink used. The heat sink must have sufficient thermal capacity to assure that the heat dissipated in the heat sink itself does not raise the device mounting-flange temperature above the rated value. The heat sink or chassis may be connected to either the positive or negative supply.

In many applications the chassis is connected to the voltage-supply terminal. If the recommended mounting hardware shown in the data bulletin for the specific solid-state device is not available, it is necessary to use either an anodized aluminum insulator having high thermal conductivity or a mica insulator between the mounting-flange and the chassis. If an insulating aluminum washer is required, it should be drilled or punched to provide the two mounting holes for the terminal pins. The burrs should then be removed from the washer and the washer anodized. To insure that the anodized insulating layer is not destroyed during mounting, it is necessary to remove the burrs from the holes in the chassis.

It is also important that an insulating bushing, such as glass-filled nylon, be used between each mounting bolt and the chassis to prevent a short circuit. However, the insulating bushing should not exhibit shrinkage or softening under the operating temperatures encountered. Otherwise the thermal resistance at the interface between transistor and heat sink may increase as a result of decreasing pressure.

PLASTIC POWER TRANSISTORS AND THYRISTORS

RCA power transistors and thyristors (SCR's and triacs) in molded-silicone-plastic packages are available in a wide range of power-dissipation ratings and a variety of package configurations. The following paragraphs provide guidelines for handling and mounting of these plastic-package devices, recommend forming of leads to meet specific mounting requirements, and describe various mounting arrangements, thermal considerations, and cleaning methods. This information is intended to augment the data on electrical characteristics, safe operating area, and performance capabilities in the technical bulletin for each type of plastic-package transistor or thyristor.

Lead-Forming Techniques

The leads of the RCA VERSAWATT in-line plastic packages can be formed to a custom shape, provided they are not indiscriminately twisted or bent. Although these leads can be formed, they are not flexible in the general sense, nor are they sufficiently rigid for unrestrained wire wrapping

Before an attempt is made to form the leads of an in-line package to meet the requirements of a specific application, the desired lead configuration should be determined, and a lead-bending fixture should be designed and constructed. The use of a properly designed fixture for this operation eliminates the need for repeated lead bending. When the use of a special bending fixture is not practical, a pair of long-nosed pliers may be used. The pliers should hold the lead firmly between the bending point and the case, but should not touch the case.

When the leads of an in-line plastic package are to be formed, whether by use of long-nosed pliers or a special bending fixture, the following precautions must be observed to avoid internal damage to the device:

1. Restrain the lead between the bending point and the plastic case to prevent relative movement between the lead and the case.
2. When the bend is made in the plane of the lead (spreading), bend only the narrow part of the lead.
3. When the bend is made in the plane perpendicular to that of the leads, make the bend at least 1/8 inch from the plastic case.
4. Do not use a lead-bend radius of less than 1/16 inch.
5. Avoid repeated bending of leads.

The leads of the TO-220AB VERSAWATT in-line package are not designed to withstand excessive axial pull. Force in this direction greater than 4 pounds may result in permanent damage to the device. If the mounting arrangement tends to impose axial stress on the leads, some method of strain relief should be devised.

Wire wrapping of the leads is permissible, provided that the lead is restrained between the plastic case and the point of the wrapping. Soldering to the leads is also allowed. The maximum soldering temperature, however, must not exceed 275°C and must be applied for not more than 5 seconds at a distance not less than 1/8 inch from the plastic case. When wires are used for connections, care should be exercised to assure that movement of the wire does not cause movement of the lead at the lead-to-plastic junctions.

The leads of RCA molded-plastic high-power packages are not designed to be reshaped. However, simple bending of the leads is permitted to change them from a standard vertical to a standard horizontal configuration, or conversely. Bending of the leads in this manner is restricted to three 90-degree bends; repeated bendings should be avoided.

Mounting

Recommended mounting arrangements and suggested hardware for the VERSAWATT transistors are given in the data bulletins for specific devices and in RCA Application Note AN-4124. When the transistor is fastened to a heat sink, a rectangular washer (RCA Part No. NR231A) is recommended to minimize distortion of the mounting flange. Excessive distortion of the flange could cause damage to the transistor. The washer is particularly important when the size of the mounting hole exceeds 0.140 inch (6-32 clearance). Larger holes are needed to accommodate insulating bushings; however, the holes should not be larger than necessary to provide hardware clearance and, in any case, should not exceed a diameter of 0.250 inch.

Flange distortion is also possible if excessive torque is used during mounting. A maximum torque of 8 inch-pounds is specified. Care should be exercised to assure that the tool used to drive the mounting screw never comes in contact with the plastic body during the driving operation. Such contact can result in damage to the plastic body and internal device connections. An excellent method of avoiding this problem is to use a spacer or combination spacer-isolating bushing which raises the screw head or nut above the top surface of the plastic body. The material used for such a spacer or spacer-isolating bushing should, of course, be carefully selected to avoid "cold flow" and consequent reduction in mounting force. Suggested materials for these bushings are diallphtalate, fiberglass-filled nylon, or fiberglass-filled polycarbonate. Unfilled nylon should be avoided.

Modification of the flange can also result in flange distortion and should not be attempted. The transistor should not be soldered to the heat sink by use of lead-tin solder because the heat required with this type of solder will cause the junction temperature of the transistor to become excessively high.

The TO-220AA plastic transistor can be mounted in commercially available TO-66 sockets, such as UID Electronics Corp. Socket No. PTS-4 or equivalent. For testing purposes, the TO-220AB in-line package can be mounted in a Jetron Socket No. DC74-104 or equivalent. Regardless of the mounting method, the following precautions should be taken:

1. Use appropriate hardware.
2. Always fasten the transistor to the heat sink before the leads are soldered to fixed terminals.
3. Never allow the mounting tool to come in contact with the plastic case.
4. Never exceed a torque of 8 inch-pounds.
5. Avoid oversize mounting holes.
6. Provide strain relief if there is any probability that axial stress will be applied to the leads.
7. Use insulating bushings to prevent hot-creep problems. Such bushings should be made of diallphthalate, fiberglass-filled nylon, or fiberglass-filled polycarbonate.

The maximum allowable power dissipation in a solid state device is limited by the junction temperature. An important factor in assuring that the junction temperature remains below the specified maximum value is the ability of the associated thermal circuit to conduct heat away from the device.

When a solid state device is operated in free air, without a heat sink, the steady-state thermal circuit is defined by the junction-to-free-air thermal resistance given in the published data for the device. Thermal considerations require that a free flow of air around the device is always present and that the power dissipation be maintained below the level which would cause the junction temperature to rise above the maximum rating. However, when the device is mounted on a heat sink, care must be taken to assure that all portions of the thermal circuit are considered.

To assure efficient heat transfer from case to heat sink when mounting RCA molded-plastic solid state power devices, the following special precautions should be observed:

1. Mounting torque should be between 4 and 8 inch-pounds.
2. The mounting holes should be kept as small as possible.
3. Holes should be drilled or punched clean with no burrs or ridges, and chamfered to a maximum radius of 0.010 inch.
4. The mounting surface should be flat within 0.002 inch/inch.
5. Thermal grease (Dow Corning 340 or equivalent) should always be used on both sides of the insulating washer if one is employed.
6. Thin insulating washers should be used. (Thickness of factory-supplied mica washers range from 2 to 4 mils).
7. A lock washer or torque washer, made of material having sufficient creep strength, should be used to prevent degradation of heat sink efficiency during life.

A wide variety of solvents is available for degreasing and flux removal. The usual practice is to submerge components in a solvent bath for a specified time. However, from a reliability stand point it is extremely important that the solvent, together with other chemicals in the solder-cleaning system (such as flux and solder covers), do not adversely affect the life of the component. This consideration applies to all non-hermetic and molded-plastic components.

It is, of course, impractical to evaluate the effect on long-term transistor life of all cleaning solvents, which are marketed with numerous additives under a variety of brand names. These solvents can, however, be classified with respect to their component parts, as either acceptable or unacceptable. Chlorinated solvents tend to dissolve the outer package and, therefore, make operation in a humid atmosphere unreliable. Gasoline and other hydrocarbons cause the

inner encapsulant to swell and damage the transistor. Alcohol and unchlorinated freons are acceptable solvents. Examples of such solvents are:

1. Freon TE
2. Freon TE-35
3. Freon TP-35 (Freon PC)
4. Alcohol (isopropanol, methanol, and special denatured alcohols, such as SDA1, SDA30, SDA34, and SDA44)

Care must also be used in the selection of fluxes for lead soldering. Rosin or activated rosin fluxes are recommended, while organic or acid fluxes are not. Examples of acceptable fluxes are:

1. Alpha Reliaros No. 320-33
2. Alpha Reliaros No. 346
3. Alpha Reliaros No. 711
4. Alpha Reliafoam No. 807
5. Alpha Reliafoam No. 809
6. Alpha Reliafoam No. 811-13
7. Alpha Reliafoam No. 815-35
8. Kester No. 44

If the completed assembly is to be encapsulated, the effect on the molded-plastic transistor must be studied from both a chemical and a physical standpoint.

RECTIFIERS AND THYRISTORS

A surge-limiting impedance should always be used in series with silicon rectifiers and thyristors. The impedance value must be sufficient to limit the surge current to the value specified under the maximum ratings. This impedance may be provided by the power transformer winding, or by an external resistor or choke.

A very efficient method for mounting thyristors utilizing packages such as the JEDEC TO-5 and "modified TO-5" is to provide intimate contact between the heat sink and at least one half of the base of the device opposite the leads. These packages can be mounted to the heat sink mechanically with glue or an epoxy adhesive, or by soldering. Soldering to the heat sink is preferable because it is the most efficient method.

The use of a "self-jigging" arrangement and a solder preform is recommended. Such an arrangement is illustrated in RCA Publication MHI-300B, "Mounting Hardware Supplied with RCA Semiconductor Devices". If each unit is soldered individually, the heat source should be held on the heat sink and the solder on the unit. Heat should be applied only long enough to permit solder to flow freely. For more detailed thyristor mounting considerations, refer to Application Note AN3822, "Thermal Considerations in Mounting of RCA Thyristors".

MOS FIELD-EFFECT TRANSISTORS

Insulated-Gate Metal Oxide-Semiconductor Field-Effect Transistors (MOS FETs), like bipolar high-frequency transistors, are susceptible to gate insulation damage by the electrostatic discharge of energy through the devices. Electrostatic discharges can occur in an MOS FET if a type with an unprotected gate is picked up and the static charge, built in the handler's body capacitance, is discharged through the device. With proper handling and applications procedures, however, MOS transistors are currently being extensively used in production by numerous equipment manufacturers in military, industrial, and consumer applications, with virtually no problems of damage due to electrostatic discharge.

In some MOS FETs, diodes are electrically connected between each insulated gate and the transistor's source. These diodes offer protection against static discharge and in-circuit transients without the need for external shorting mechanisms. MOS FETs which do not include gate-protection diodes can be handled safely if the following basic precautions are taken:

1. Prior to assembly into a circuit, all leads should be kept shorted together either by the use of metal shorting springs attached to the device by the vendor, or by the insertion into conductive material such as "ECCOSORB* LD26" or equivalent.
   (NOTE: Polystyrene *insulating* "SNOW" is not sufficiently conductive and should not be used.)
2. When devices are removed by hand from their carriers, the hand being used should be grounded by any suitable means, for example, with a metallic wristband.
3. Tips of soldering irons should be grounded.
4. Devices should never be inserted into or removed from circuits with power on.

INTEGRATED CIRCUITS

In any method of mounting integrated circuits which involves bending or forming of the device leads, it is extremely important that the lead be supported and clamped between the bend and the package seal, and that bending be done with care to avoid damage to lead plating. In no case should the radius of the bend be less than the diameter of the lead, or in the case of rectangular leads,such as those used in RCA 14-lead and 16-lead flat-packages, less than the lead thickness. It is also extremely important that the ends of the bent leads be straight to assure proper insertion through the holes in the printed-circuit board.

COS/MOS (Complementary-Symmetry MOS) Integrated Circuits

1. Handling

All COS/MOS gate inputs have a resistor/diode gate protection network. All transmission gate inputs and all outputs have diode protection provided by inherent p-n junction diodes. These diode networks at input and output interfaces fully protect COS/MOS devices from gate-oxide failure (70 to 100 volt limit) for static discharge or signal voltage up to 1 to 2 kilovolts under most transient or low-current conditions.

Although protection against electrostatic effects is provided by built-in circuitry, the following handling precautions should be taken:

1. Soldering-iron tips and test equipment should be grounded.
2. Devices should not be inserted in non-conductive containers such as conventional plastic snow or trays.

*Trade Mark: Emerson and Cumming, Inc.

2. Operating

Unused Inputs

All unused input leads must be connected to either V_{SS} or V_{DD}, whichever is appropriate for the logic circuit involved. A floating input on a high-current type, such as the CD4009A, CD4010A, not only can result in faulty logic operation, but can cause the maximum power dissipation of 200 milliwatts to be exceeded and may result in damage to the device. Inputs to these types, which are mounted on printed-circuit boards that may temporarily become unterminated, should have a pull-up resistor to V_{SS} or V_{DD}. A useful range of values for such resistors is from 0.2 to 1 megohm.

Input Signals

Signals shall not be applied to the inputs while the device power supply is off unless the input current is limited to a steady state value of less than 10 milliamperes.

Output Short Circuits

Shorting of outputs to V_{SS} or V_{DD} can damage many of the higher-output-current COS/MOS types, such as the CD4007A, CD4009A, and CD4010A. In general, these types can all be safely shorted for supplies up to 5 volts, but will be damaged (depending on type) at higher power-supply voltages. For cases in which a short-circuit load, such as the base of a p-n-p or an n-p-n bipolar transistor, is directly driven, the device output characteristics given in the published data should be consulted to determine the requirements for a safe operation below 200 milliwatts.

For detailed COS/MOS IC Handling Considerations, refer to Application Note ICAN-6000 "Handling Considerations for MOS Integrated Circuits".

SOLID STATE CHIPS

Solid state chips, unlike packaged devices, are non-hermetic devices, normally fragile and small in physical size, and therefore, require special handling considerations as follows:

1. Chips must be stored under proper conditions to insure that they are not subjected to a moist and/or contaminated atmosphere that could alter their electrical, physical, or mechanical characteristics. After the shipping container is opened, the chip must be stored under the following conditions:
   A. Storage temperature, 40^{o}C max.
   B. Relative humidity, 50% max.
   C. Clean, dust-free environment.
2. The user must exercise proper care when handling chips to prevent even the slightest physical damage to the chip.
3. During mounting and lead bonding of chips the user must use proper assembly techniques to obtain proper electrical, thermal, and mechanical performance.
4. After the chip has been mounted and bonded, any necessary procedure must be followed by the user to insure that these non-hermetic chips are not subjected to moist or contaminated atmosphere which might cause the development of electrical conductive paths across the relatively small insulating surfaces. In addition, proper consideration must be given to the protection of these devices from other harmful environments which could conceivably adversely affect their proper performance.

Design Considerations for the RCA-S6431M Silicon Controlled Rectifier In High-Current Pulse Applications

by

D. E. Burke and G. W. Albrecht

Silicon controlled rectifiers (SCR's) are often used in pulse circuits in which the ratio of peak to average current is large. Typical applications include radar pulse modulators, inverters, and switching regulators. The limiting parameter in such applications often is the time required for forward current to spread over the whole area of the junction. Losses in the SCR are high, and are concentrated in a small region until the entire junction area is in conduction. This concentration produces undesirable high temperatures.

The RCA-S6431M SCR is specially designed to achieve rapid utilization of the full junction area. The rating curves and calculations presented in this Note allow the designer to make full use of the high switching capability of this device.

Circuits

A typical SCR pulse modulator circuit is shown in Fig.1. Basic waveforms for the circuit are shown in Fig.2. The capacitors of the energy-storage network are charged by the dc supply. The SCR is triggered by pulses from the gate-trigger generator No.1, and the energy-storage network discharges through an inductance and the load (transformer). Fig.2 shows that the discharge of the storage network (t_1 - t_2) is oscillatory; the half-sine-wave shape is characteristic of a single LC-section energy-storage network.

For turn-off, the load is "mismatched" to the discharge-circuit impedance so that a negative voltage is developed on the capacitor at the end of the pulse. The negative voltage reverse-biases the SCR. This form of turn-off is indicated in Fig.2(b).

When the energy-storage network is recharged from the dc supply, the SCR returns to the forward-blocking condition and is ready for the next cycle. The recharge interval (t_3 - t_4) may be delayed by use of a charging SCR, as shown in Figs.1 and 2 (t_2 - t_3). This technique reduces the turn-off time requirements for the SCR. The rate of recharge influences the dv/dt requirements for the SCR.

Figs.1 and 2 illustrate only one of a great variety of pulse circuits, each of which would have particular requirements for the SCR. A common requirement would be to pass forward currents with particular emphasis on shape and magnitude.

Turn-On Time Definitions

In the idealized waveforms of Fig.2, the SCR is presented as a perfect switch. Actually, it exhibits a finite resistance prior to turn-on, a delay after the introduction of the trigger pulse, and appreciable resistance after turn-on.

The common definition of turn-on time adequately covers the delay and rise-time intervals of the turn-on process, but does not consider the rate of current spread over the junction area and its attendant dissipation. Because the dissipation after turn-on is an important consideration in pulse circuits, turn-on definitions in themselves provide no indication of the switching capability of the SCR.

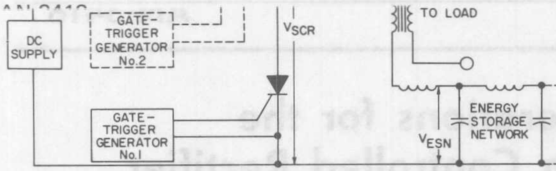


Fig.1 - Basic pulse modulator circuit.

As an example, the rise-time portion of turn-on is defined as the time interval between the 10-per-cent and 90-per-cent points on the current wave shape when the SCR is triggered on in a circuit that has rated forward voltage and sufficient resistance to limit the current to rated values. For a 600-volt device, the end of the turn-on interval occurs when the forward voltage drop across the SCR is 60 volts. This value contrasts with the steady-state forward voltage of only 1 or 2 volts under such conditions. An interval many times greater than the turn-on time may be required before the forward voltage drop reduces to the steady-state level.

Switching Capability

Because several different physical effects occur in the SCR during the complete turn-on interval, it is convenient to divide the total turn-on time into three discrete intervals: delay time t_1, fall time t_2, and equalizing time t_3. These intervals are shown in Fig.3. The solid lines represent device turn-on to low steady-state forward current, in which case equalization effects are not pronounced. The dashed lines represent SCR turn-on to high currents, in which case t_3 becomes a noticeable interval.

The first interval (t_1 or delay time) results from the initiation of forward conduction between the p-type base and the n-type emitter (i.e., injection of holes through the gate-cathode junction and injection of electrons through the cathode-gate junction). This interval depends to a large extent upon the level of gate current used to turn on the SCR. The use of a trigger pulse greater than the minimum gate-current requirement of the SCR minimizes delay time and reduces the range of the delay times encountered between individual SCR's, the variability of delay with temperature, and the variability of cycle-to-cycle delay or jitter.* There are no significant power losses in the SCR during delay. The delay interval is primarily of interest because of its effect on system performance.

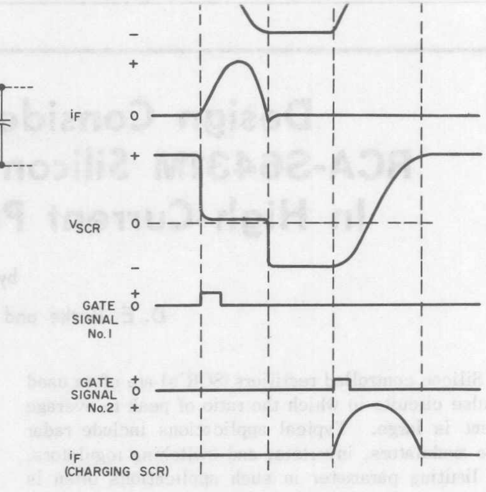


Fig.2 - Idealized waveforms for pulse-discharge circuit.

The second interval (t_2 or fall time) depends on the initiation of forward conduction between the p-type emitter and the n-type emitter (i.e., anode-to-cathode current). When this phenomenon is isolated from current effects, as described later, the duration of the voltage fall time measured from the 90-per-cent to the 10-per-cent point is less than 0.3 microsecond. Voltage fall time is illustrated in Fig.4 for a range of initial voltages.

The flow of forward current during the voltage fall time results in power loss in this interval. The magni-

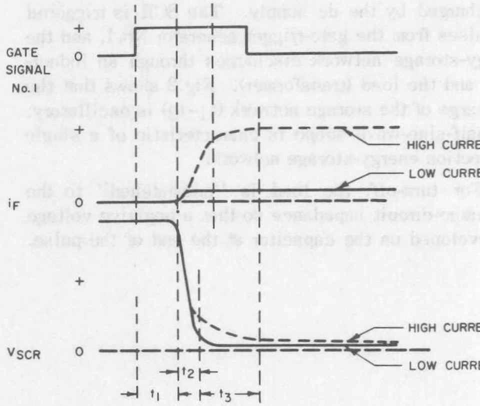


Fig.3 - Actual SCR wave shapes during turn-on.

* The technical bulletin for the S6431M contains information on maximum trigger-pulse magnitudes for various pulse widths for this device. This Note discusses gating characteristics of RCA SCR's in more detail.

fall time of voltage in the SCR, the device experiences high peak dissipation during the short turn-on interval.

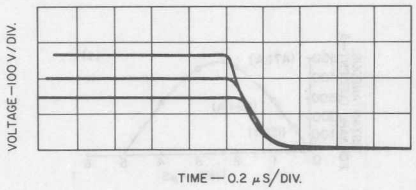


Fig.4 - Illustration of voltage fall time (low forward current).

The third discrete interval during turn-on, equalization time (t_3 of Fig.3), represents the time required for the current to spread over the junction area. The forward current resulting from the initial voltage fall is concentrated in a small area of the junction and spreads gradually over the entire area. The rate of increase in the active junction area depends on the geometry and the junction parameters, and is influenced by the levels of driving voltage and current. In general, the time required for full utilization of junction area represents a considerably longer interval than t_1 (delay) or t_2 (fall).

For given conditions of current rise time, current level, and gate drive, t_3 could be defined as the time required for forward voltage to decrease to a given multiple of the final steady-state value under a constant-current pulse. Such a definition would be more indicative of switching capability than the conventional definition of turn-on time as the time required for forward ON-state voltage to decrease to a percentage of the initial blocking voltage. At best, however, either type of definition has only limited usefulness to the user.

Characteristics and Ratings

Because the major factor in the rating of SCR's for pulse applications is the initial forward-voltage drop, the RCA-S6431M is rated specifically for this characteristic. Figs.5 and 6 show two families of rating curves which make it possible to calculate the power loss per pulse and the average power loss for a particular current-pulse shape, magnitude, and repetition rate desired. Figs.7 and 8 show maximum allowable repetition rates and pulse amplitudes for several pulse shapes, and are useful as a quick estimating guide for the pulse-current switching capability of the S6431M SCR.

Limits must also be imposed upon the instantaneous temperature rise of the junction over the average case

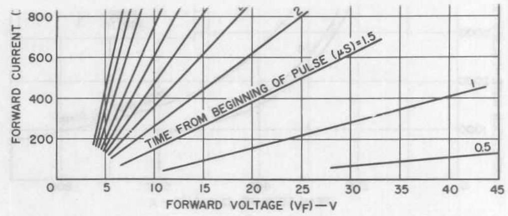


Fig.5 - Forward voltage as a function of forward voltage at various times after the initiation of turn-on.

temperature and upon the differential temperature stresses in the device. Fig.9 shows the allowable maximum current for the S6413M at any time after the initiation of the current pulse. This curve, together with those in Figs.7 and 8, gives an indication of the feasibility of using the S6431M in a high-current pulse application.

Fig.10 illustrates the calculation of device dissipation and pulse repetition rate for a particular pulse

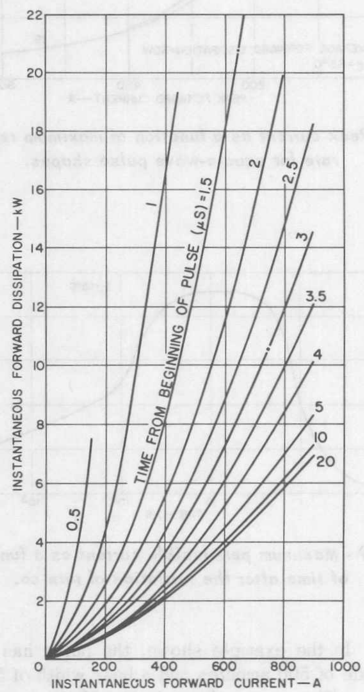


Fig.6 - Instantaneous forward dissipation as a function of current at various times after the initiation of turn-on.

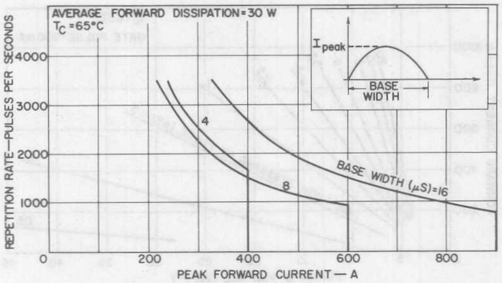


Fig.7 - Peak current as a function of maximum repetition rate for sine-wave pulse shapes.

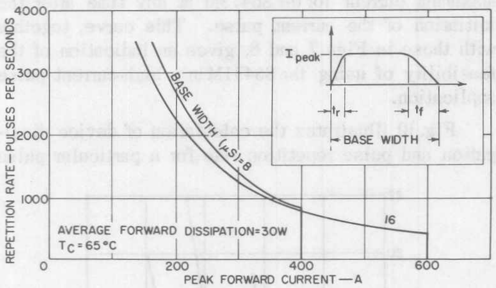


Fig.8 - Peak current as a function of maximum repetition rate for square-wave pulse shapes.

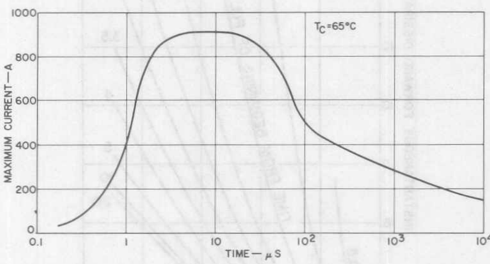
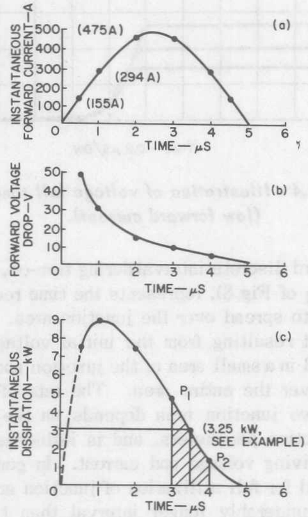


Fig.9 - Maximum permissible current as a function of time after the initiation of turn-on.

shape. In the example shown, the pulse has a peak magnitude of 500 amperes and a base width of 5 microseconds. The curves shown in Fig.10 are constructed from the curves of Figs.5 and 6 by means of a series of readings at different time intervals (delay and fall regions are neglected). A step-by-step approximate integral approach is then used to obtain the watt-seconds-per-pulse measurements shown in the table. For a repetition rate of 1000 pulses per second, the average forward dissipation is 24.37 watts for the current pulse specified. This value is within the rating of 30 watts for the S6431M at a case temperature



(d)

TIME INTERVAL (μS)	DISSIPATION FOR INTERVAL mW-S	TOTAL DISSIPATION FOR ONE PULSE mW-S	AVERAGE DISSIPATION AT 1000 C/S REP. RATE (W)	MAXIMUM REP. RATE FOR 30W DISSIPATION (C/S)
0—0.5	1.87			
0.5—1	4.12			
1—2	8.25	24.37	24.37	1225
2—3	6.18			
3—4	3.25			
4—5	0.70			

EXAMPLE: AVERAGE FORWARD WATT-SECOND DISSIPATION DURING 3 μS TO 4 μS INTERVAL:
$(4-3) \times 10^{-6}$ S $\times 3.25 \times 10^{3}$ W = 3.25 mW-S

Fig.10 - Sample calculation of forward dissipation.

of 65°C. At higher case temperatures the total dissipation must be decreased, as shown in Fig.11.

Because the interval of highest dissipation occurs at the beginning of the current pulse, reduction in the magnitude of current during this time increases the over-all switching capability of the SCR. The current may be reduced by use of a saturable reactor in the pulse-discharge circuit which has sufficient unsaturated volt-second capacity to present a high impedance for one to two microseconds. The current is then small, and dissipation is limited, until the junction area in conduction increases to include an appreciable percentage of the total cathode. By the time the reactor saturates and high pulse current results, the cathode

area in conduction is adequate to handle the high current with low dissipation.

The rate of current spread over the cathode area depends upon several factors, one of which is the level of current. Therefore, the use of a delay reactor to keep forward current low also delays the spread of current to some extent and subtracts from its beneficial effects. The maximum benefit can be achieved by reduction of the inductance of the reactor prior to saturation, or by addition of another impedance in parallel with the reactor, to effect a compromise between the initial current level and dissipation and the rate of current-density equalization. The curves in this Note do not represent the use of a delay reactor.

In addition to the power loss in the SCR caused by forward current, the total dissipation in the device includes forward and reverse blocking losses and probably reverse recovery losses during the turn-off process. The reverse recovery losses depend upon several factors, such as forward-current amplitude, rate of decrease of forward current, reverse-current flow, rate of rise of reverse voltage, and reverse-voltage amplitude. Because reverse losses are circuit-dependent, they can best be evaluated in a working circuit.

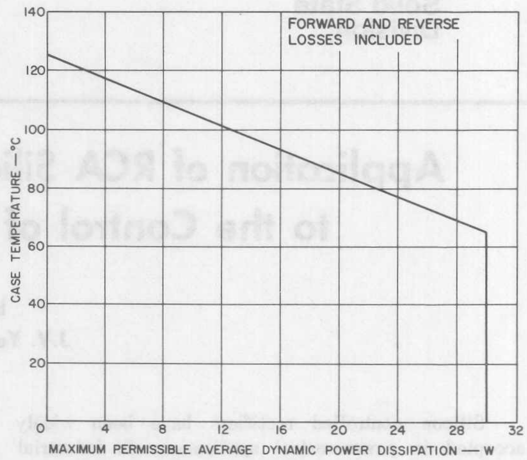


Fig.11 - Maximum average total power dissipation as a function of case temperature.

Application of RCA Silicon Controlled Rectifiers to the Control of Universal Motors

by

J.V. Yonushka

Silicon controlled rectifiers have been widely accepted in power-control applications in industrial systems where high-performance requirements justify the economics of the application. Historically, in the commercial high-volume market, economic considerations have precluded the use of the SCR. However, with the development of a family of SCR's by RCA designed specifically for mass-production economy and rated for 120- and 240-volt line operation, the use of these devices in controls for many types of small electric motors has been made economically feasible. The controls can be designed to provide good performance, maximum efficiency, and high reliability in compact packaging arrangements.

The control circuits discussed in the following text are typical of the many possible circuits applicable to electric motor control. A general description including the typical characteristics of universal motors is given. Speed control by use of phase-angle variations is discussed; schematic diagrams are given, and the advantages and limitations of each circuit are contrasted. A chart of available SCR's is shown at the end of the Note.

Universal Motors

Many fractional horsepower motors are series-wound "universal" motors, so named because of their ability to operate directly from either ac or dc power sources. Fig.1 is a schematic of this type of motor operated from an ac supply. Because most domestic applications today require 60-hertz power, universal motors are usually designed to have optimum performance characteristics at this frequency. Most universal motors run faster at a given dc voltage than at the same 60-hertz ac voltage.

The field winding of a universal motor, whether distributed or lumped (salient pole), is in series with the armature and external circuit, as shown in Fig.1.

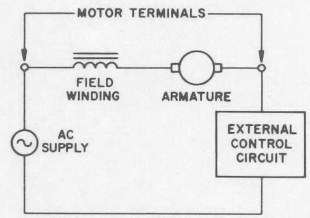


Fig.1 - Schematic diagram for a series-wound universal motor.

The current through the field winding produces a magnetic field which cuts across the armature conductors. The action of this field in opposition to the field set up by the armature current subjects the individual conductors to a lateral thrust which results in armature rotation.

AC operation of a universal motor is possible because of the nature of its electrical connections. As the ac source voltage reverses every half-cycle, the

magnetic field produced by the field winding reverses its direction simultaneously. Because the armature windings are in series with the field windings through the brushes and commutating segments, the current through the armature winding also reverses. Because both the magnetic field and armature current are reversed, the direction of the lateral thrust on the armature windings remains constant.

As the armature rotates through the magnetic field, a voltage opposite to the impressed voltage is induced in the individual conductors. Counter emf produced in the armature conductors is therefore proportional to motor speed. In half-wave operation, during the nonconducting half-cycle of an SCR, the rotating armature still produces a counter emf because of the residual magnetism of the field poles. In some of the applications described, the counter emf of an operating motor is used as a means of providing speed regulation to compensate for changing shaft loads.

The current through an operating motor armature depends upon the difference between the impressed voltage (emf) and the counter emf. The current that flows through a universal motor when it is initially energized is large because there is no rotation to generate a counter emf in the armature windings. The starting current is limited only by the impedance of the armature and field windings. The ratio of peak starting current to peak running current can be as high as 10:1.

The speed of a series motor automatically adjusts itself so that the difference between the impressed voltage and the counter emf is sufficient to permit enough current to flow to develop the torque required by the load. At very light loads, or at no load, the current through a universal motor is small. To maintain a small current through the motor, the counter emf must be high enough so that only a small difference exists between the impressed voltage and the counter emf. The small current through the motor also results in a weak magnetic-field flux because it is the current through the field winding that produces the flux. The weakened magnetic-field flux tends to make the motor speed increase even further to produce the high counter emf required to maintain a small motor current. It would appear, then, that universal motors should tend to "run away" at no load. This run-away does not occur, however, because motors of this type usually offer enough friction and windage loss to limit the maximum attainable no-load speed to a safe value.

When a mechanical load is attached to a universal motor, the current through the motor must increase to provide the increased torque required by the load. An increase in the current through the motor requires an increase in the difference between the impressed voltage and the counter emf. This increased difference can only be brought about by a reduction in counter emf derived from a decrease in speed. For an uncompensated universal motor, the full-load speed is approximately 60 per cent or less of the no-load speed.

The torque developed by a universal motor is a direct result of the magnitude of magnetic-field flux and armature current. For fixed mechanical loads, the starting torque of a universal motor is high because the armature current at starting time is high; at "stall" conditions, because of the large armature current, the torque is again high. The stall torque of a series motor can be as high as 10 times the continuous rated torque.

Because torque and armature current influence the speed of a universal motor, it is possible under certain operating conditions to vary the impressed voltage and influence operating characteristics of the motor. For increased mechanical loads, an increase in the impressed voltage produces a larger armature current and tends to keep the speed constant. High starting torque, adjustable speed characteristics, and small size are distinct advantages of a universal motor over a comparably rated single-phase induction motor. Typical performance characteristic curves for a universal motor are shown in Fig.2.

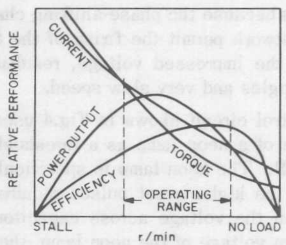


Fig.2 - Typical performance curves for a universal motor.

Use of Silicon Controlled Rectifiers for Motor Control

One of the simplest and most efficient means of varying the impressed voltage to a load on an ac power system is by control of the conduction angle of an SCR placed in series with the load. Typical curves showing the variation of motor speed with SCR conduction angle for both half-wave and full-wave impressed motor voltages are illustrated in Fig.3. If desired, a switch may be installed in the half-wave circuits so that the SCR and its related control circuit can be bypassed for full-power operation.

Half-Wave Control

There are many good circuits available for half-wave control of universal motors; their attributes and limitations are described in detail below. The circuits are divided into two classes; regulating and non-regulating. Regulation in this instance implies load sensing and compensation of the system to prevent changes in

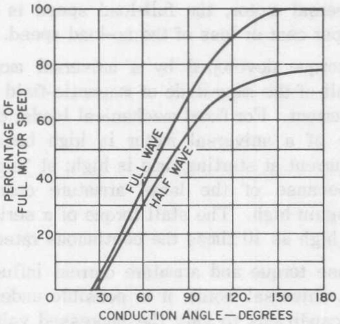
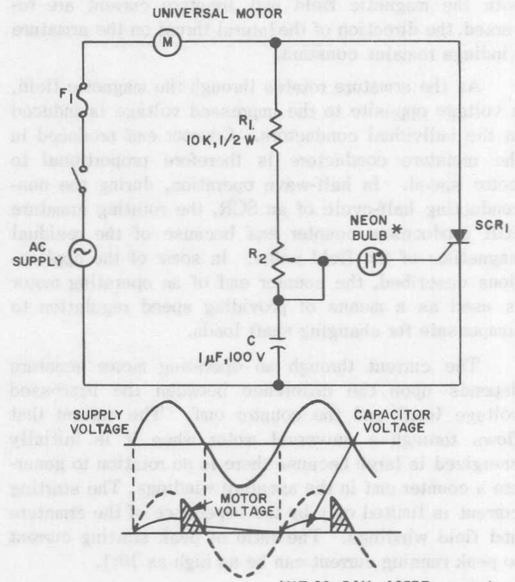


Fig.3 - Typical performance curves for a universal motor with phase-angle control.

motor speed. The type of regulation provided by each circuit is stated and compared to other circuits.

The half-wave proportional control circuit shown in Fig.4 is a non-regulating circuit whose function depends upon an RC delay network for gate phase-lag control. This circuit is better than simple resistance firing circuits because the phase-shifting characteristics of the RC network permit the firing of the SCR beyond the peak of the impressed voltage, resulting in small conduction angles and very slow speed.

The control circuit shown in Fig.4 uses the breakdown voltage of a neon lamp as a threshold setting for firing the SCR. The neon lamp is specifically designed for handling the high-current pulses required to trigger SCR's. When the voltage across capacitor C reaches the breakdown voltage of the neon lamp, the lamp fires, and C discharges through the lamp to its maintaining voltage. At this point, the lamp again reverts to its high-impedance state. The discharge of the capacitor from breakdown to maintaining voltage of the neon lamp provides a current pulse of sufficient magnitude to fire the SCR. Once the SCR has fired, the voltage across the phase-shift network reduces to the forward voltage drop of the SCR for the remainder of the half-cycle. The range of conduction angles of this circuit is approximately 30 to 150 degrees. The high breakdown voltage of the neon lamp improves noise rejection and prevents erratic firing of the SCR because of brush noises on the voltage supply lines. Table I shows components for the circuit of Fig.4.



*NE-83, 5AH, A057B, or equiv.

Fig.4 - Half-wave motor control with no regulation.

The circuit shown in Fig.5 reduces spread in gate turn-on characteristics. This circuit depends upon the fast switching characteristics of transistors such as those used in the two-transistor regenerative trigger network shown. The phase-shift characteristics are still retained to provide conduction angles less than 90 degrees through the RC network of R_1, R_2, and C_1. Resistor R_3 provides turn-on current to the base of Q_1 when the voltage across C_1 becomes large enough during the positive half-cycle. The base current in Q_1 turns on this transistor. Transistor Q_1 then supplies base

TABLE I - COMPONENTS FOR CIRCUIT SHOWN IN FIG.4.

AC SUPPLY	AC CURRENT	F_1	CR_1	R_2	SCR_1
120 V	1 A	3 AG, 1.5 A, Quick Act	D1201B	100 K, 1/2 W	RCA-2N3528
120 V	3 A	3 AB, 3 A	D1201B	100 K, 1/2 W	RCA-2N3228
120 V	7 A	3 AB, 7 A	D1201B	100 K, 1/2 W	RCA-2N3669
240 V	1 A	3 AG, 1.5 A, Quick Act	D1201D	150 K, 1/2 W	RCA-2N3529
240 V	3 A	3 AB, 3 A	D1201D	150 K, 1/2 W	RCA-2N3525
240 V	7 A	3 AB, 7 A	D1201D	150 K, 1/2 W	RCA-2N3670

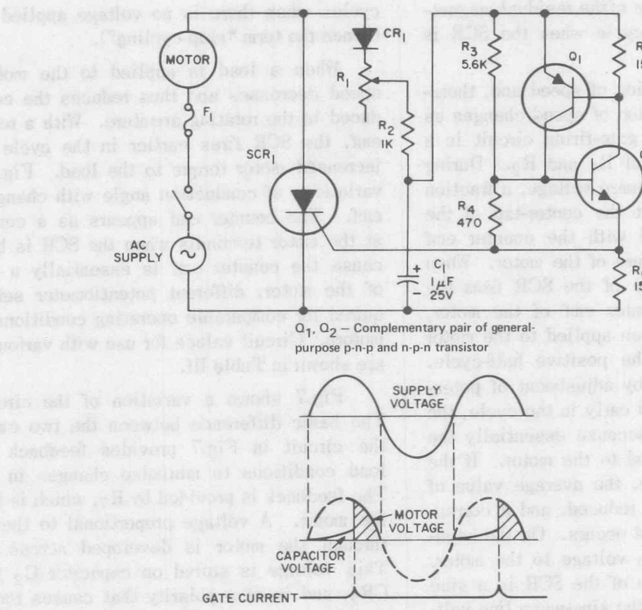


Fig.5 - Half-wave motor control with no regulation.

current to Q_2. When Q_2 turns on, it supplies more base current to Q_1. This regenerative action leads to the rapid saturation of transistors Q_1 and Q_2. Capacitor C_1 discharges through the saturated transistors into the gate of the SCR. When the SCR fires, the remaining portion of the positive half-cycle of ac power is applied to the motor. Speed control is accomplished by adjustment of potentiometer R_1. With component values as shown on the schematic diagram in Fig.5, the threshold voltage for firing the circuit is approximately 8 volts; the maximum conduction angle is approximately 170 degrees. Table II shows components for the circuit with various RCA SCR's.

Fig.6 shows a fundamental circuit of direct-coupled SCR control with voltage feedback. This circuit is highly effective for speed control of universal motors. The circuit makes use of the counter emf (cemf) induced

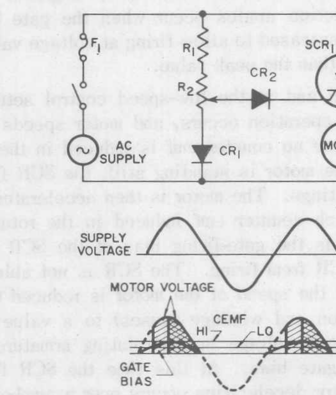


Fig.6 - Half-wave motor control with regulation.

TABLE II - COMPONENTS FOR CIRCUIT SHOWN IN FIG.5.

AC SUPPLY	AC CURRENT	F_1	CR_1	R_1	SCR_1
120 V	1 A	3 AG, 1.5 A, Quick Act	D1201B	75 K, 1/2 W	RCA-2N3528
120 V	3 A	3 AB, 3 A	D1201B	75 K, 1/2 W	RCA-2N3228
120 V	7 A	3 AB, 7 A	D1201B	75 K, 1/2 W	RCA-2N3669
240 V	1 A	3 AG, 1.5 A, Quick Act	D1201D	150 K, 1/2 W	RCA-2N3529
240 V	3 A	3 AB, 3 A	D1201D	150 K, 1/2 W	RCA-2N3525
240 V	7 A	3 AB, 7 A	D1201D	150 K, 1/2 W	RCA-2N3670

in the rotating armature because of the residual magnetism in the motor on the half-cycle when the SCR is blocking.

The counter emf is a function of speed and, therefore, can be used as an indication of speed changes as mechanical load varies. The gate-firing circuit is a resistance network consisting of R_1 and R_2. During the positive half-cycle of the source voltage, a fraction of the voltage is developed at the center-tap of the potentiometer and is compared with the counter emf developed in the rotating armature of the motor. When the bias developed at the gate of the SCR from the potentiometer exceeds the counter emf of the motor, the SCR fires. AC power is then applied to the motor for the remaining portion of the positive half-cycle. Speed control is accomplished by adjustment of potentiometer R_1. If the SCR is fired early in the cycle, the motor operates at high speed because essentially the full rated line voltage is applied to the motor. If the SCR is fired later in the cycle, the average value of voltage applied to the motor is reduced, and a corresponding reduction in motor speed occurs. On the negative half-cycle, the SCR blocks voltage to the motor. The voltage applied to the gate of the SCR is a sine wave because it is derived from the sine-wave line voltage. The minimum conduction angle occurs at the peak of the sine wave and is restricted to 90 degrees. Increasing conduction angles occur when the gate bias to the SCR is increased to allow firing at voltage values which are less than the peak value.

At no load and at the low-speed control setting, "skip-cycling" operation occurs, and motor speeds are erratic. Because no counter emf is induced in the armature when the motor is standing still, the SCR fires at low bias settings. The motor is then accelerated to a point at which counter emf induced in the rotating armature exceeds the gate-firing bias of the SCR and prevents the SCR from firing. The SCR is not able to fire again until the speed of the motor is reduced (because of friction and windage losses) to a value for which the induced voltage in the rotating armature is less than the gate bias. At this time the SCR fires again. The motor deceleration occurs over a number of cycles when there is no voltage applied to the motor, (hence the term "skip cycling").

When a load is applied to the motor, the motor speed decreases and thus reduces the counter emf induced in the rotating armature. With a reduced counter emf, the SCR fires earlier in the cycle and provides increased motor torque to the load. Fig.6 also shows variations of conduction angle with changes in counter emf. The counter emf appears as a constant voltage at the motor terminals when the SCR is blocking. Because the counter emf is essentially a characteristic of the motor, different potentiometer settings are required for comparable operating conditions for different motors. Circuit values for use with various RCA SCR's are shown in Table III.

Fig.7 shows a variation of the circuit in Fig.5. The basic difference between the two circuits is that the circuit in Fig.7 provides feedback for changing load conditions to minimize changes in motor speed. The feedback is provided by R_7, which is in series with the motor. A voltage proportional to the peak current through the motor is developed across the resistor. This voltage is stored on capacitor C_2 through diode CR_2, and is of a polarity that causes the bias on the resistance network of R_3 and R_4 to change in accordance with the load on the motor. With an increasing motor load, the speed tends to decrease. This decrease in motor speed causes more current to flow through the motor armature and field windings. When the current flowing through R_7 increases, the voltage stored on capacitor C_2 increases in the positive direction. This increase in capacitor voltage causes the transistors to conduct earlier in the cycle, to fire the SCR, and to provide a greater portion of the power cycle to the motor. With a decreasing load, the motor current decreases and the voltage stored by capacitor C_2 decreases. The transistors and SCR then conduct later in the cycle. The resultant reduction in the average power supplied to the motor causes a reduced torque to the smaller load. Because motor current is a function of the motor itself, resistor R_7 has to be matched with the motor rating to provide optimum feedback for load compensation. Resistor R_7 may range from 0.1 ohm for

TABLE III - COMPONENTS FOR CIRCUIT SHOWN IN FIG.6.

AC SUPPLY	AC CURRENT	F_1	CR_1, CR_2	R_1	R_2	SCR_1
120 V	1 A	3 AG, 1.5 A, Quick Act	D1201B	5.6 K, 2 W	1 K, 2 W	RCA-2N3528
120 V	3 A	3 AB, 3 A	D1201B	5.6 K, 2 W	1 K, 2 W	RCA-2N3228
120 V	7 A	3 AB, 7 A	D1201B	2.7 K, 4 W	500, 2 W	RCA-2N3669
240 V	1 A	3 AG, 1.5 A, Quick Act	D1201D	10 K, 5 W	1 K, 2 W	RCA-2N3529
240 V	3 A	3 AB, 3 A	D1201D	10 K, 5 W	1 K, 2 W	RCA-2N3525
240 V	7 A	3 AB, 7 A	D1201D	5.6 K, 7.5 W	500, 2 W	RCA-2N3670

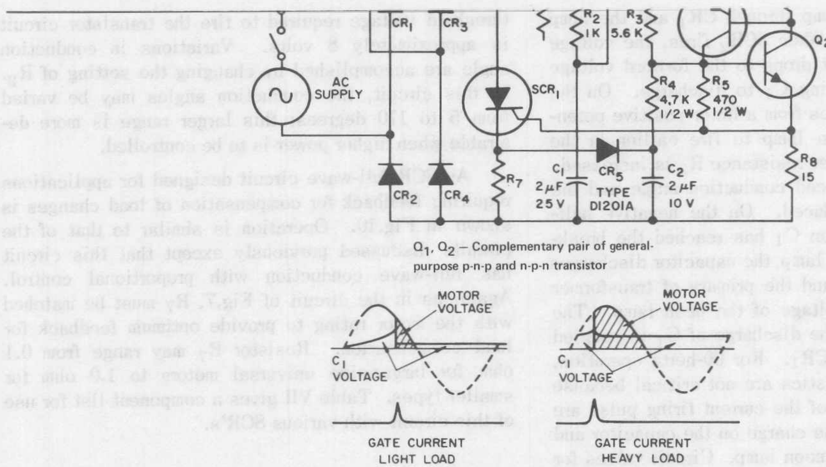


Fig.7 - Half-wave motor control using two-transistor regenerative triggering with regulation.

larger-size universal motors to 1.0 ohm for smaller types. Circuit values for use with various RCA SCR's are shown in Table IV.

Full-Wave Control

This section discusses the application of SCR's to full-wave motor control. Two SCR's are usually required to provide full-wave control.

A very simple SCR full-wave proportional control circuit is shown in Fig.8. Again, ac phase shifting and neon triggering are used to provide gate phase-angle control; a small pulse transformer is utilized for isolation. The circuit provides a symmetrical output for both halves of the ac input voltage because the same electrical components are used in the phasing network for both SCR gates. Because the SCR gate circuits are completely isolated from each other, the cross-talk problem usually associated with gate firing circuits using transformer coupling and bi-directional trigger devices is avoided. There is a hysteresis effect associated with this circuit because C_1 charges to alternate positive and negative values. As R_2 decreases from

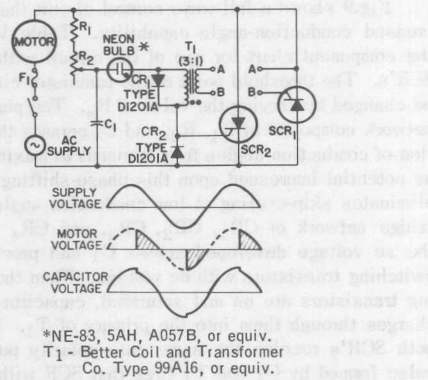


Fig.8 - Full-wave motor control with no regulation.

TABLE IV - COMPONENTS FOR CIRCUIT SHOWN IN FIG.7.

AC SUPPLY	AC CURRENT	F_1	CR_1	R_1	SCR_1
120 V	1 A	3 AG, 1.5 A, Quick Act	D1201B	75 K, 1/2 W	RCA-2N3528
120 V	3 A	3 AB, 3 A	D1201B	75 K, 1/2 W	RCA-2N3228
120 V	7 A	3 AB, 7 A	D1201B	75 K, 1/2 W	RCA-2N3669
240 V	1 A	3 AG, 1.5 A, Quick Act	D1201D	150 K, 1/2 W	RCA-2N3529
240 V	3 A	3 AB, 3 A	D1201D	150 K, 1/2 W	RCA-2N3525
240 V	7 A	3 AB, 7 A	D1201D	150 K, 1/2 W	RCA-2N3670

its maximum value, C_1 charges to a higher voltage on each half cycle. When the positive half-cycle voltage on C_1 reaches the breakdown potential of the neon lamp, the lamp fires, allowing C_1 to discharge to the maintaining voltage of the lamp through CR_1 and the lamp into the gate of SCR_2. When SCR_2 fires, the voltage across the control circuit drops to the forward voltage value of the SCR, allowing C_1 to discharge. On the next half-cycle, C_1 charges from a lower positive potential and allows the neon lamp to fire earlier in the cycle. If the potentiometer resistance R_2 is increased, the SCR's fire at a reduced conduction angle and the hysteresis effect is produced. On the negative half-cycle, when the charge on C_1 has reached the breakdown potential of the neon lamp, the capacitor discharges through CR_2, the lamp, and the primary of transformer T_1 to the maintaining voltage of the neon lamp. The current pulse formed by the discharge of C_1 is coupled by T_1 into the gate of SCR_1. For 60-hertz operation, the transformer characteristics are not critical because the magnitude and shape of the current firing pulse are determined primarily by the charge on the capacitor and the characteristics of the neon lamp. Circuit values for use with various RCA SCR's are shown in Table V. Conduction angles obtained with this circuit vary from 30 to 150 degrees; at the maximum conduction angle, the voltage impressed upon the load (universal motor) is approximately 95 per cent of the input rms voltage.

Fig.9 shows a full-wave control circuit that has increased conduction-angle capability. Table VI shows the component chart for use of the circuit with various SCR's. The threshold point of the transistor circuit can be changed by varying the value of R_3. The phase-shift network composed of R_1, R_2, and C_1 permits the variation of conduction angles from minimum to maximum. An ac potential impressed upon this phase-shifting network eliminates skip-cycling at low conduction angles. The bridge network of CR_1, CR_2, CR_3, and CR_4 rectifies the ac voltage developed across C_1 and provides the switching transistors with dc voltage. When the switching transistors are on and saturated, capacitor C_1 discharges through them into the primary of T_1. Because both SCR's receive the same gate polarity pulse, the pulse formed by C_1 and T_1 fires that SCR with a positive potential at the anode. When the SCR fires, the remaining portion of the half-cycle is applied to the load. On the alternate half-cycle, the other SCR turns on. With the component values shown in Fig.9, the threshold voltage required to fire the transistor circuit is approximately 8 volts. Variations in conduction angle are accomplished by changing the setting of R_2. In this circuit, the conduction angles may be varied from 5 to 170 degrees; this larger range is more desirable when higher power is to be controlled.

An SCR full-wave circuit designed for applications requiring feedback for compensation of load changes is shown in Fig.10. Operation is similar to that of the circuits discussed previously except that this circuit has full-wave conduction with proportional control. Again, as in the circuit of Fig.7, R_7 must be matched with the motor rating to provide optimum feedback for load compensation. Resistor R_7 may range from 0.1 ohm for larger-size universal motors to 1.0 ohm for smaller types. Table VII gives a component list for use of this circuit with various SCR's.

Ratings and Limitations

Package size and environment limit the voltage and current capabilities and, consequently, the power-dissipation abilities of an SCR. Maximum temperature ratings usually depend on the use of a heat sink of a particular size at a prescribed ambient or case temperature.

The main cause of heat within an SCR operating at 60 hertz is the forward current and voltage drop during conduction. Under steady-state conditions, the heat generated within the device must be balanced by the flow of heat to the heat sink and the ambient air. If more heat is generated within the SCR than can be dissipated by the case and the heat sink, the junction temperature increases and forward blocking capabilities are lost. Under these conditions the SCR may break down thermally in the reverse direction, causing damage to the SCR pellet. An increase in heat-sink size to maintain the balance between heat generated and heat dissipated assures reliable performance of the SCR.

TABLE V - COMPONENTS FOR CIRCUIT SHOWN IN FIG.8.

AC SUPPLY	AC CURRENT	F_1	R_1	R_2	C_1	SCR_1, SCR_2
120 V	1.5 A	3 AG, 2 A, Quick Act	1 K, 1/2 W	50 K, 1/2 W	0.22 μF, 100 V	RCA-2N3528
120 V	5 A	3 AB, 5 A	1 K, 1/2 W	50 K, 1/2 W	0.22 μF, 100 V	RCA-2N3228
120 V	10 A	3 AB, 10 A	1 K, 1/2 W	25 K, 2 W	0.47 μF, 100 V	RCA-2N3669
240 V	1.5 A	3 AG, 2 A, Quick Act	1 K, 1 W	50 K, 2 W	0.22 μF, 100 V	RCA-2N3529
240 V	5 A	3 AB, 5 A	1 K, 1 W	50 K, 2 W	0.22 μF, 100 V	RCA-2N3525
240 V	10 A	3 AB, 10 A	1 K, 1 W	25 K, 4 W	0.47 μF, 100 V	RCA-2N3670

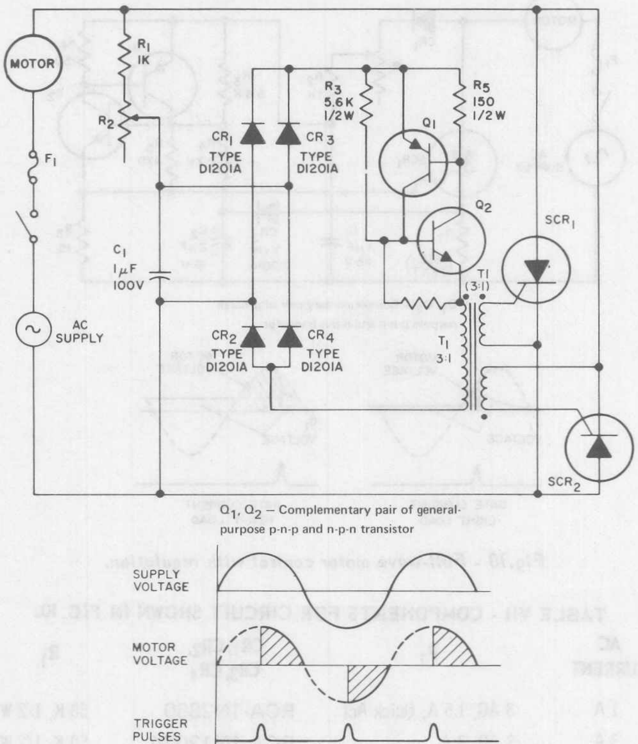


Fig.9 - Full-wave motor control with no regulation in which the conduction angle can be varied from 5 to 180 degrees.

The current ratings for the circuits using the 2N3528 and 2N3529 SCR's are based upon measurements made with these devices mounted by their electrical leads with the package in free air. The current ratings for the circuits using the other SCR types are based upon measurements made with the SCR's mounted on an aluminum heat sink having an equivalent dimension of 3 by 3 by 1/16 inches.

TABLE VI COMPONENTS FOR CIRCUIT SHOWN IN FIG.9.

AC SUPPLY	AC CURRENT	F_1	R_2	SCR_1, SCR_2
120 V	1.5 A	3 AG, 2 A, Quick Act	75 K, 1/2 W	RCA-2N3528
120	5 A	3 AB, 5 A	75 K, 1/2 W	RCA-2N3228
120 V	10 A	3 AB, 10 A	75 K, 1/2 W	RCA-2N3669
240 V	1.5 A	3 AG, 2 A, Quick Act	150 K, 1/2 W	RCA-2N3529
240 V	5 A	3 AB, 5 A	150 K, 1/2 W	RCA-2N3525
240 V	10 A	3 AB, 10 A	150 K, 1/2 W	RCA-2N3670

The SCR can be mounted on a single-plate heat sink or on a metal chassis. In chassis mounting the package housing and heat sink can be insulated from the chassis by a mica washer, as shown in Fig.11. The use of silicone grease or other similar material between the SCR housing and the heat sink provides a better thermal contact and more efficient heat dissipation. If heat dissipation is critical, a finned heat sink should

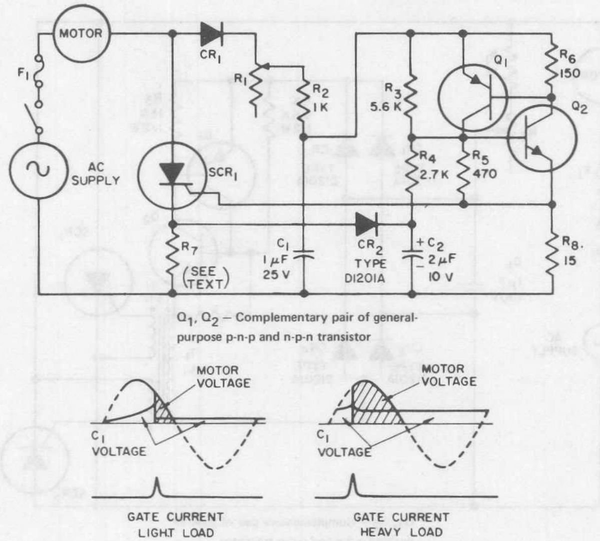


Fig.10 - Full-wave motor control with regulation.

TABLE VII - COMPONENTS FOR CIRCUIT SHOWN IN FIG.10.

AC SUPPLY	AC CURRENT	F_1	CR_1, CR_2, CR_3, CR_4	R_1	SCR_1
120 V	1 A	3 AG, 1.5 A, Quick Act	RCA-1N2860	50 K, 1/2 W	RCA-2N3528
120 V	3 A	3 AB, 3 A	RCA-1N1202A	50 K, 1/2 W	RCA-2N3228
120 V	7 A	3 AB, 7 A	RCA-1N1202A	50 K, 1/2 W	RCA-2N3669
240 V	1 A	3 AG, 1.5 A, Quick Act	RCA-1N2862	100 K, 1/2 W	RCA-2N3529
240 V	3 A	3 AB, 3 A	RCA-1N1204A	100 K, 1/2 W	RCA-2N3525
240 V	7 A	3 AB, 7 A	RCA-1N1204A	100 K, 1/2 W	RCA-2N3670

be used. Heat-sink size may be reduced in any application if moving air can be provided at the SCR mounting site.

If a universal motor is operated at low speed under a heavy mechanical load, it may stall and cause heavy current flow through the SCR. For this reason, low-speed heavy-load conditions should be allowed to exist for only a few seconds to prevent possible circuit damage. In any case, fuse ratings should be carefully observed and limited to the types and values indicated in the tables accompanying the circuits in this Note.

Practical heat sinks, packaging, available fuse characteristics, and motor overload and stall performance have been considered and are reflected in the current ratings shown for the circuits in this Note; these current values should not be exceeded.

Nameplate data for some universal motors are given in developed horsepower to the load. This mechanical designation can be converted into its electrical current equivalent through the following procedure.

Internal motor losses are taken into consideration by assigning a figure of merit. This figure, 0.5, represents motor operation at 50-per-cent efficiency, and indicates that the power input to the motor is twice the power delivered to the load. With this figure of merit and the input voltage V_{ac}, the rms input current to the motor can be calculated as follows:

$$\text{rms current} = \frac{\text{mechanical horsepower} \times 746}{0.5\ V_{ac}}$$

For an input voltage of 120 volts, the rms input current becomes:

$$\text{rms current} = \text{horsepower} \times 12.4$$

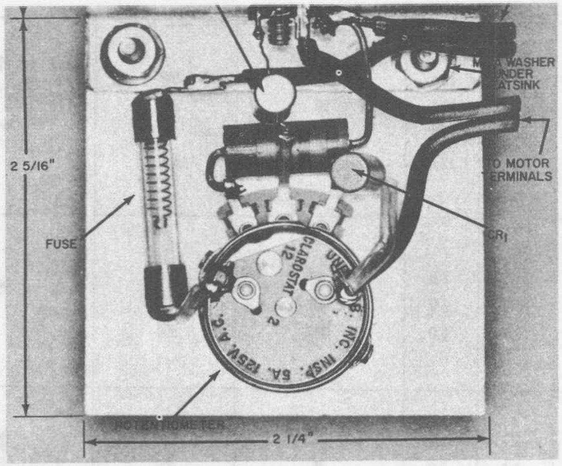


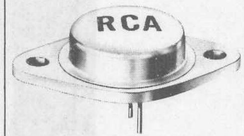
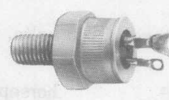
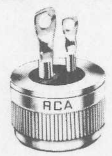
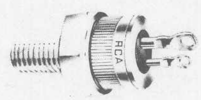
Fig.11 - Photograph of half-wave motor speed control.

For an input voltage of 240 volts, the rms input current becomes:

rms current = horsepower x 6.2

The circuits in this Note should not be used with universal motors that have calculated rms current exceeding the values given in the tables. The circuits will accommodate universal motors with ratings up to 3/4 horsepower at 120 volts input and up to 1-1/2 horsepower at 240 volts input.

RCA SILICON CONTROLLED RECTIFIERS

RCA TYPE NO.	CURRENT - A ave.	CURRENT - A rms	CASE TEMP. - °C	VOLTAGE - V	JEDEC PACKAGE
2N3668	8	12.5	80	100	 TO-3
2N3669	8	12.5	80	200	
2N3670	8	12.5	80	400	
2N4103	8	12.5	80	600	
2N3528	1.3	2.0	25*	200	 TO-8
2N3529	1.3	2.0	25*	400	
2N4102	1.3	2.0	25*	600	
2N3228	3.2	5.0	75	200	 TO-66
2N3525	3.2	5.0	75	400	
2N4101	3.2	5.0	75	600	
2N681 - 2N690	16	25	65	25 - 600	 TO-48
2N1842A - 2N1850A	10	16	80	25 - 500	
2N3870	22	35	65	100	 Press Fit
2N3871	22	35	65	200	
2N3872	22	35	65	400	
2N3873	22	35	65	600	
2N3896	22	35	65	100	 Stud Mounted
2N3897	22	35	65	200	
2N3898	22	35	65	400	
2N3899	22	35	65	600	

*Ambient temperature.

Circuit Factor Charts for RCA Thyristor Applications (SCR's and Triacs)

by

B. J. Roman and J. M. Neilson

In the design of circuits using thyristors (SCR's and triacs), it is often necessary to determine the specific values of peak, average, and rms current flowing through the device. Although these values are readily determined for conventional rectifiers, the calculations are more difficult for thyristors because the current ratios become functions of both the conduction angle and the firing angle of the device.

This Note presents charts that show several current ratios as functions of conduction and firing angles for some of the basic SCR and triac circuits. Examples are given of the use of these charts in the design of half-wave, full-wave ac, full-wave dc, and three-phase half-wave circuits using RCA thyristors. Current and voltage waveforms for the various circuits are also included, as well as curves of per-cent ripple in load current and voltage.

Current-Ratio Curves

Figs. 1, 2, and 3 show current-ratio curves for a single-phase half-wave SCR circuit with resistive load, a single-phase SCR or triac full-wave circuit with resistive load, and a three-phase half-wave SCR circuit with resistive load, respectively. These curves relate average current I_{avg}, rms current I_{rms}, and peak current I_{pk} to a reference current I_o. This reference current I_o is a constant of the circuit equal to the peak source voltage V_{pk} divided by the load resistance R_L; it represents the maximum value that the current can obtain and corresponds to the peak of the sine wave. The peak current I_{pk} is the current which appears at the thyristor during its period of forward conduction. For conduction angles greater than 90 degrees, I_{pk} is equal to I_o; for conduction angles smaller than 90 degrees, I_{pk} is smaller than I_o.

The curves of Figs. 1, 2, and 3 can be used in a number of ways to calculate desired current values. For example, they can be used to determine the peak or rms current in a thyristor when a specified average current is to be delivered to a load during a given part of the conduction period. It is also possible to work backwards and determine the necessary period of conduction to maintain a specified peak-to-average current ratio in a particular application. Another use is the calculation of rms current at various conduction angles when it is necessary to determine the power delivered to a load, or power losses in transformers, motors, leads, or bus bars. Although the curves represent device currents, they are equally useful for calculation of load current and voltage ratios.

For use of these curves, it is first necessary to identify the unknown or desired parameter. The values of the parameters fixed by the circuit specifications are then determined, and the appropriate curve is used to obtain the unknown quantity as a function of two of the fixed parameters. Examples of the use of the curves are given to illustrate their versatility.

Half-Wave SCR Circuit

In the single-phase half-wave circuit shown in Fig. 4, an SCR is used to control power from a sinusoidal ac source of 120 volts rms (170 volts peak) into a 2.8-ohm load. This application requires a load current which can be varied from 2 to 25 amperes. It is necessary to determine the range of conduction angles required to obtain this range of load current.

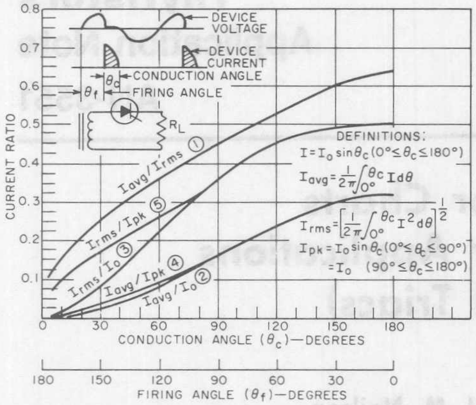


Fig. 1 - SCR current ratios for single-phase, half-wave conduction with resistive load.

The reference current I_o is first calculated, as follows:

$$I_o = \frac{V_{pk}}{R_L} = \frac{170}{2.8} = 61 \text{ amperes}$$

The ratio of rms current I_{rms} to I_o is then calculated for the maximum and minimum load-current requirements, as follows:

$$(I_{rms}/I_o)_{max} = (25/61) = 0.41$$

$$(I_{rms}/I_o)_{min} = (2/61) = 0.033$$

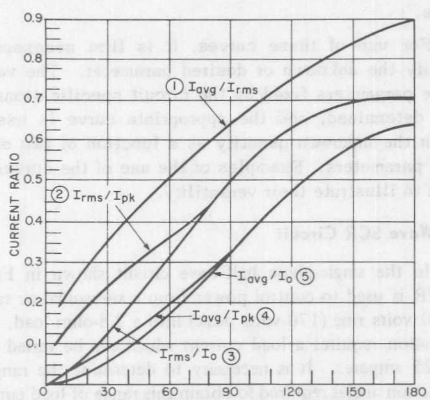


Fig. 2 - SCR or triac current ratios for single-phase, full-wave conduction with resistive load.

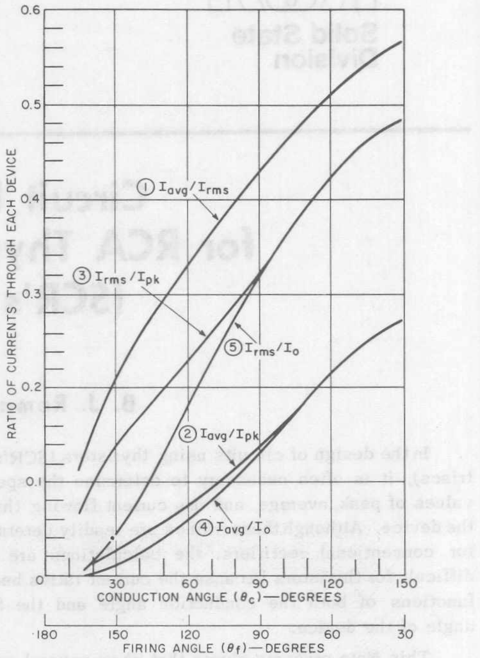


Fig. 3 - SCR current ratios for three-phase half-wave circuit with resistive load.

The conduction angles corresponding to the ratios can then be determined by use of curve 3 in Fig. 1:

$$\theta_c \text{ max} = 106^\circ$$

$$\theta_c \text{ min} = 15^\circ$$

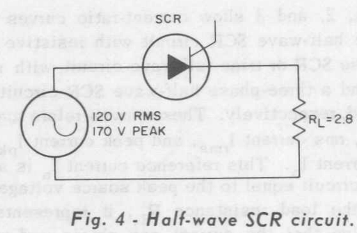


Fig. 4 - Half-wave SCR circuit.

Full-Wave AC Triac Circuit

Fig. 5 shows a circuit in which a triac is used to control the power to a 20-ohm resistive load. It is desired to find the range of conduction angles the gate circuit must be capable of supplying to provide continuous variation in load power between 5 and 97 percent of the full power which the load could draw.

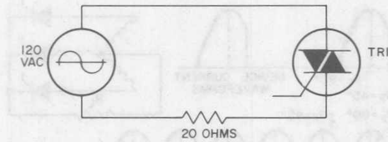


Fig. 5 - Full-wave triac control circuit.

Full power P is given by

$$P = \frac{V_{rms}^2}{R_L} = \frac{120^2}{20} = 720 \text{ watts}$$

Therefore, the 5- and 97-per-cent power points are as follows:

$$P_5 = 36 \text{ watts}$$

$$P_{97} = 698 \text{ watts}$$

The rms current corresponding to each point is given by

$$I_5 = \sqrt{P_5/R_L} = \sqrt{36/20} = 1.3 \text{ amperes rms}$$

$$I_{97} = \sqrt{P_{97}/R_L} = \sqrt{698/20} = 5.9 \text{ amperes rms}$$

The reference current I_o is determined as follows:

$$I_o = \frac{V_{peak}}{R_L} = \frac{120 \times \sqrt{2}}{20} = 8.5 \text{ amperes}$$

The current ratios for the 5- and 97-per-cent power levels then become

at 5%, $I_{rms}/I_o = 1.3/8.5$ (amperes) = 0.153

at 97%, $I_{rms}/I_o = 5.9/8.5$ (amperes) = 0.695

Because the circuit shown in Fig. 5 is a full-wave circuit, the calculated current ratios are used in curve 3 of Fig. 2 to determine the required conduction angles:

at 5% power, conduction angle = 35°

at 97% power, conduction angle = 150°

Thus, the load power is continuously variable from 5 to 97 per cent of full load if the gate circuit is constructed so that the conduction angle can be varied between 35 and 150 degrees. This variation is within the range which can be obtained with a simple trigger-diode type of gate circuit.

Full-Wave DC SCR or Triac Circuit

Fig. 6 shows several different SCR circuits and a triac circuit which can be used to supply a constant dc output to a variable load resistance with an ac input of 64 volts rms. It is desired to determine the variation in conduction angle required to maintain the average load current at a constant value of 30 amperes while the load resistance varies between 0.12 and 1.80 ohms.

The reference currents are calculated for maximum and minimum values of load resistance, as follows:

$$I_{o_{max}} = \frac{V_{peak}}{R_{L_{min}}} = \frac{64\sqrt{2}}{0.12} = 750 \text{ amperes}$$

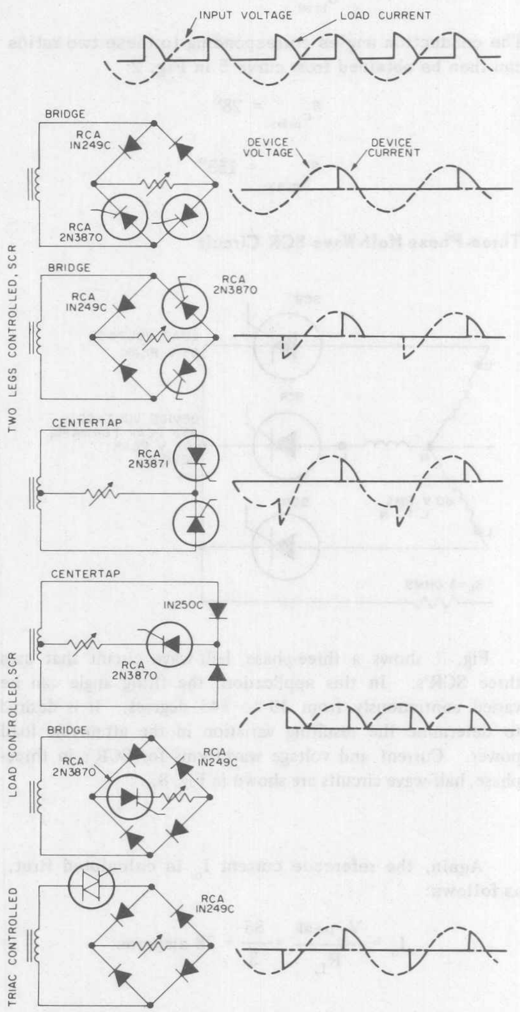


Fig. 6 - Typical current and voltage waveforms for single-phase, full-wave thyristor circuits with resistive load.

$$I_{o_{min}} = \frac{V_{peak}}{R_{L_{max}}} = \frac{64\sqrt{2}}{1.80} = 50 \text{ amperes}$$

The ratios of I_{avg} to I_o for an average load current of 30 amperes are then calculated as follows:

$$\frac{I_{avg}}{I_{o_{max}}} = \frac{30}{750} = 0.04$$

$$\frac{I_{avg}}{I_{o_{min}}} = \frac{30}{50} = 0.60.$$

The conduction angles corresponding to these two ratios can then be obtained from curve 5 in Fig. 2:

$$\theta_{c_{min}} = 28^{\circ}$$

$$\theta_{c_{max}} = 153^{\circ}$$

Three-Phase Half-Wave SCR Circuit

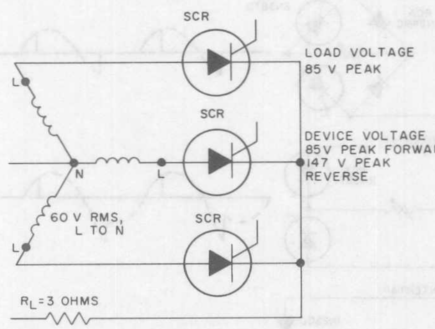


Fig. 7 shows a three-phase, half-wave circuit that uses three SCR's. In this application, the firing angle can be varied continuously from 30 to 145 degrees. It is desired to determine the resulting variation in the attainable load power. Current and voltage waveforms for SCR's in three-phase, half-wave circuits are shown in Fig. 8.

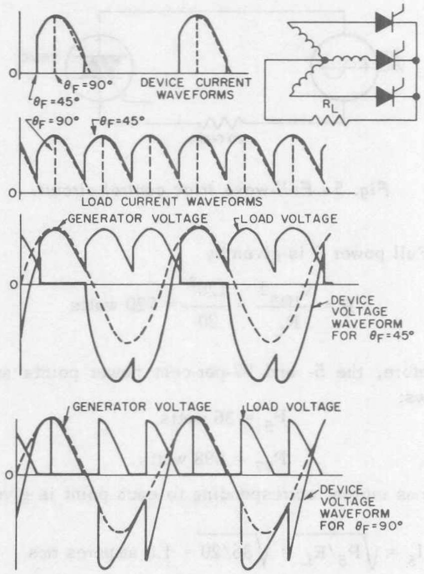


Fig. 8 Typical current and voltage waveforms for three-phase, half-wave SCR circuit with resistive load.

Again, the reference current I_o is calculated first, as follows:

$$I_o = \frac{V_{L}peak}{R_L} = \frac{85}{3} = 28 \text{ amperes}$$

Current ratios at the extremes of the firing range are determined from Fig. 3. For the specified firing angles, the current ratios are given by

$$\frac{I_{rms}}{I_o} = 0.49 \text{ for } \theta_f = 30^{\circ}$$

$$\frac{I_{rms}}{I_o} = 0.06 \text{ for } \theta_f = 145^{\circ}$$

These ratios, together with the reference current, are then used to determine the range of rms current in the SCR's, as follows:

$$I_{rms}\ max = (0.49)\ (28) = 13.7 \text{ amperes}$$

$$I_{rms}\ min = (0.06)\ (28) = 1.7 \text{ amperes}$$

In this type of circuit, the rms load current is equal to the rms SCR current multiplied by the square root of three. The load power P, therefore, is given by

$$P = (I_{rms}\sqrt{3})^2\ (R)$$

The range of load power can then be determined as follows:

$$P_{max} = 1700 \text{ watts}$$

$$P_{min} = 27 \text{ watts}$$

In other words, the load power can be varied continuously from 27 to 1700 watts.

Per-Cent Ripple in Load

The choice of a rectifier circuit for a particular application often depends on the amount of rectifier "ripple" (undesired fluctuation in the dc output caused by an ac component) that can be tolerated in the application. Fig. 9 shows per-cent ripple in load current and voltage for single-phase half-wave, single-phase full-wave, and three-phase half-wave thyristor circuits.

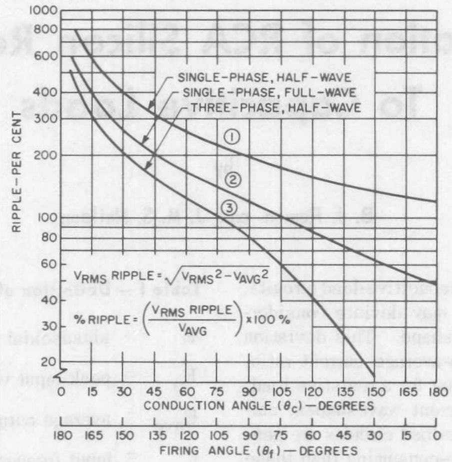


Fig. 9 - Output ripple in thyristor circuits as a function of conduction and firing angles.

Application of RCA Silicon Rectifiers To Capacitive Loads

by

B. J. Roman and J. M. S. Neilson

When rectifiers are used in capacitive-load circuits, the rectifier current waveforms may deviate considerably from their true sinusoidal shape. This deviation is most evident for the peak-to-average current ratio, which is somewhat higher than that for a resistive load. Because of the variation in current waveshapes, calculations of ratings for capacitive-load circuits are generally more complicated and time-consuming than those for resistive-load rectifier circuits.

This Note describes a simplified rating system which allows designers to calculate the characteristics of capacitive-load rectifier circuits quickly and accurately. The effect of the addition of a series limiting resistance to such circuits and the importance of the ratio of the limiting resistance to capacitive reactance are described, and curves of rectifier current ratios are presented as functions of the effective ratio. Typical design examples are given, and output-ripple considerations are discussed. Table I defines the symbols used in the equations and calculations.

Design of Capacitor-Input Circuits

In the design of a rectifier circuit, the output voltage and current, the input voltage, and the ripple and regulation requirements are usually specified. The transformer and the type of rectifier to be used are selected by the designer, and the load resistance is determined on the basis of the output voltage and current requirements. The ripple requirements are satisfied by use of a capacitor to shunt the load R_L, as shown in Fig. 1. The waveforms for this circuit indicate that the voltage across the capacitor E_C coincides with the supply voltage E when the rectifier is conducting in the forward direction. A high initial diode surge current I_S occurs because the capacitor acts as a short circuit when power is first applied. The diode turns off at the peak of the curve (point0), and remains off until E_C is again equal to E (point A). The turn on point t_{on} is determined by the time constant R_LC, and affects the average, peak, and rms currents through the device.

As stated above, the low forward voltage drop of silicon rectifiers may result in a very high surge of current when the capacitive load is first energized. Although the generator or source impedance may be high

Table I – Definition of Symbols

E	=	sinsusoidal input voltage ($E = E_o \sin \omega t$)
E_o	=	peak input voltage
E_{avg}	=	average output voltage
f	=	input frequency (Hz)
ω	=	angular frequency of input ($\omega = 2\pi f$ radians per second)
t	=	time counted from beginning of cycle
R_S	=	limiting resistance
R_L	=	load resistance
C	=	load capacitance
I_o	=	absolute peak current through rectifier
I_{pk}	=	actual peak current through rectifier
Irms	=	root-mean-squafe current through rectifier
I_{avg}	=	average current through rectifier
n	=	charge factor; 1 for half-wave circuit, ½ for doubler circuit, 2 for full-wave circuit

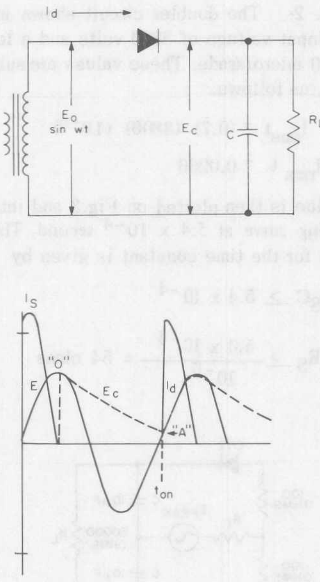


Fig.1 - Circuit showing use of capacitor to shunt the load, and resulting waveforms.

enough to protect the rectifier, in some cases additional resistance must be added to the generator-rectifier-capacitor loop, as shown in Fig.2, to keep the surge within device ratings. The waveforms in Fig.2 show that the capacitor voltage E_C is no longer coincident with the steady state supply voltage E during any part of the cycle. The sum of the additional limiting resistance plus the source resistance is referred to as the total limiting resistance R_S. The ratio of R_S to capacitive reactance $1/\omega C$ is an important consideration in capacitor-input rectifier circuits; ideally, R_S should be much smaller than $1/\omega C$. The magnitude of R_S required in a particular circuit is calculated as described below.

Calculation of Limiting Resistance

The value of resistance required to protect the rectifier is calculated from the surge rating chart for the particular device used. Fig. 3 shows surge rating charts for diffused junction stack rectifiers CR1 and CR2. Each point on the curves defines a surge rating by indicating the maximum time for which the device can safely carry a specific value of rms current.

With a capacitive load, maximum surge current occurs if the circuit is switched on when the input voltage is near its peak value. When the time constant R_SC of the surge loop is much smaller than the period of the

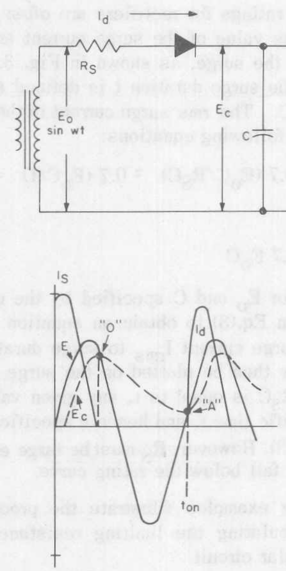


Fig.2 Circuit showing addition of limiting resistance, and resulting waveforms.

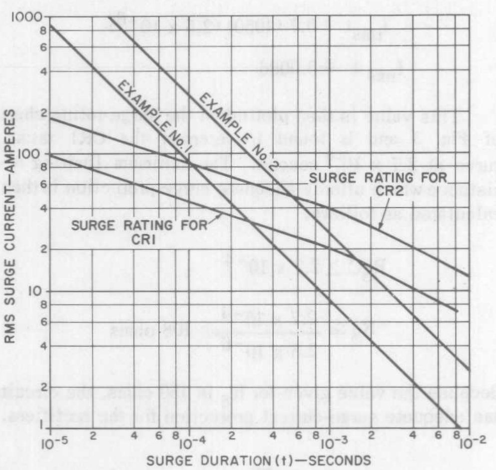


Fig.3 - Surge-rating chart used for calculation of limiting resistance.

input voltage, the peak current is equal to the peak input voltage E_o divided by the limiting resistance R_S, and the resulting surge I_S approximates an exponentially decaying current with the time constant R_SC, as follows:

$$I_S = (E_o/R_S)\ \exp\ (-1/R_SC) \tag{1}$$

proximated by the following equations:

$$I_{rms} = 0.7\,(E_oC/R_SC) = 0.7\,(E_oC/t) \qquad (2)$$

and

$$I_{rms}\,t = 0.7\,E_oC \qquad (3)$$

The values for E_o and C specified by the circuit design are used in Eq.(3) to obtain an equation which relates the rms surge current I_{rms} to surge duration t. This equation may then be plotted on the surge rating chart. Because R_SC is equal to t, any given value of R_S defines a specific time t, and hence a specific point on the plot of Eq.(3). However, R_S must be large enough to make this point fall below the rating curve.

The following examples illustrate the procedure described for calculating the limiting resistance required in a particular circuit.

Example No. 1: Fig. 4 shows a half-wave rectifier circuit that has a 60-Hz frequency and a peak input voltage E_o of 4950 volts. The values of E_o and C are substituted in Eq.(3) to obtain the value of $I_{rms}t$, as follows:

$$I_{rms}t = 0.7\,(4950)\,(2.5 \times 10^{-6})$$

$$I_{rms}\,t = 0.0086$$

This value is then plotted on the surge-rating chart of Fig. 3 and is found to intersect the CR1 rating curve at 2.7×10^{-4} second. The minimum limiting resistance which affords adequate surge protection is then calculated as follows:

$$R_SC \geq 2.7 \times 10^{-4}$$

$$R_S \geq \frac{2.7 \times 10^{-4}}{2.5 \times 10^{-6}} = 108 \text{ ohms}$$

Because the value given for R_S is 150 ohms, the circuit has adequate surge-current protection for the rectifiers.

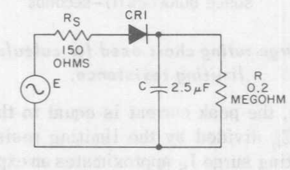


Fig.4 - Half-wave rectifier circuit (E = 3500 V rms, E_o = 3820 V, f = 60 Hz).

$$I_{rms}t = (0.7)\,(3800)\,(10^{-5})$$

$$I_{rms}\,t = 0.0266$$

This value is then plotted on Fig.3 and intersects the CR2 rating curve at 5.4×10^{-4} second. Therefore, the equation for the time constant is given by

$$R_SC \geq 5.4 \times 10^{-4}$$

$$R_S \geq \frac{5.4 \times 10^{-4}}{10^{-5}} = 54 \text{ ohms}$$

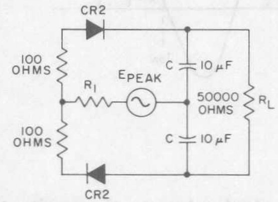


Fig.5 - Voltage-doubler rectifier circuit (E = 2700 V rms, E_o = 3820 V, f = 60 Hz).

Calculation of Rectifier Current

The design of rectifier circuits using capacitive loads often requires the determination of rectifier current waveforms in terms of average, rms, and peak currents. These waveforms are needed for calculations of circuit parameters, selection of components, and matching of circuit parameters with rectifier ratings. Actual calculation of rectifier current is a rather lengthy process. A much more direct process is to use the current-relationship charts shown in Figs. 6 and 7. These curves can be readily used to find peak or rms current if the average current is known, or vice versa.

The ratios of peak-to-average current and rms-to-average current are shown in Fig. 6 as functions of the circuit constants $n\omega CR_L$ and R_S/nR_L. The quantity ωCR_L is the ratio of resistive-to-capacitive reactance in the load, and the quantity R_S/R_L is the ratio of limiting resistance to load resistance. The factor n is referred to as the "charge factor" and is simply a multiplier which allows the chart to be used for various circuit configurations. It is equal to unity for half-wave circuits, ½ for doubler circuits, and 2 for full-wave circuits. (These values actually represent the relative quantity of charge delivered to the capacitor on each cycle).

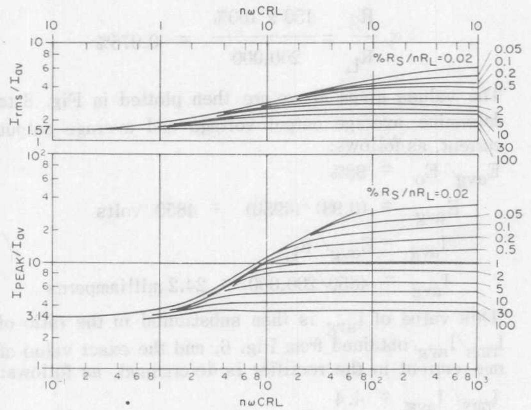


Fig.6 - Relation of peak, average, and rms rectifier currents in capacitor-input circuits.

In many silicon rectifier circuits, R_S may be completely neglected when compared with the magnitude of R_L. In such circuits, the calculation of rectifier current is even more simplified by the use of Fig. 7, which gives current ratios under the limitation that R_S/R_L approaches zero. Even if this condition is not fully satisfied, the use of Fig. 7 merely indicates a higher peak and higher rms current than will actually flow in the circuit; as a result, the rectifiers will operate more conservatively than calculated. This simplified solution can be used whenever a rough approximation or a quick check is needed on whether a rectifier will fit the application. When more exact information is needed, Fig.6 should be used.

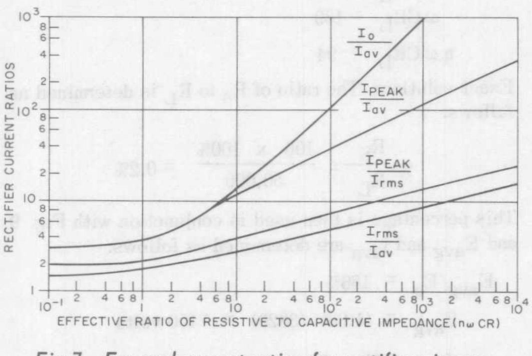


Fig.7 - Forward-current ratios for rectifiers in capacitor-input circuits in which the limiting resistance is much less than 1/ ωC.

Average output voltage E_{avg} is another important quantity because it can be used to find average output current. The relations between input and output voltages for half-wave, voltage-doubler, and full-wave circuits are given in Figs. 8,9, and 10, respectively. Output ripple is shown in Fig. 11 for all three circuits. Although these curves were originally calculated for vacuum-tube rectifiers, they are equally applicable to silicon rectifier circuits.

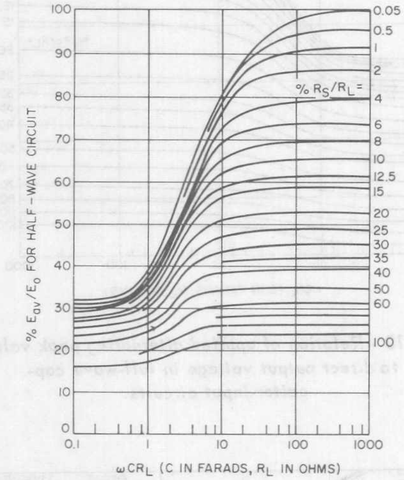


Fig.8 - Relation of applied alternating peak voltage to direct output voltage in half-wave capacitor-input circuits.

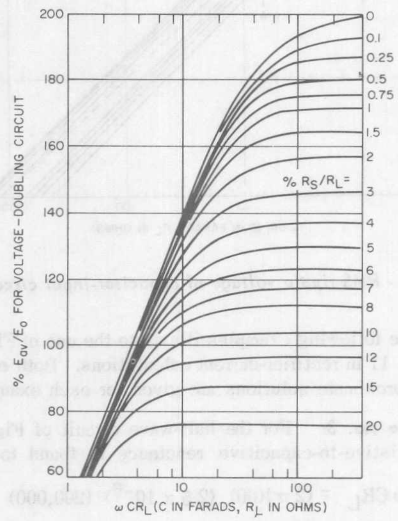


Fig.9 - Relation of applied alternating peak voltage to direct output voltage in capacitor-input voltage doubler circuits.

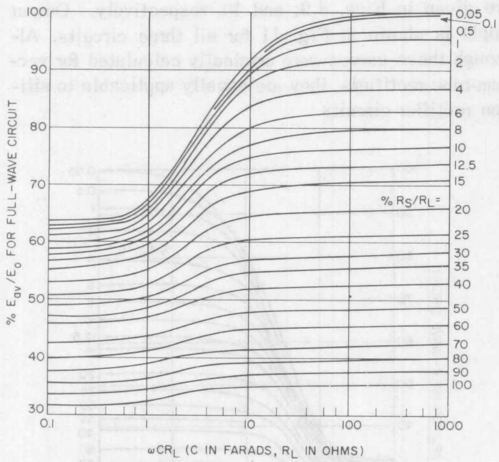


Fig. 10 - Relation of applied alternating peak voltage to direct output voltage in full-wave capacitor-input circuits.

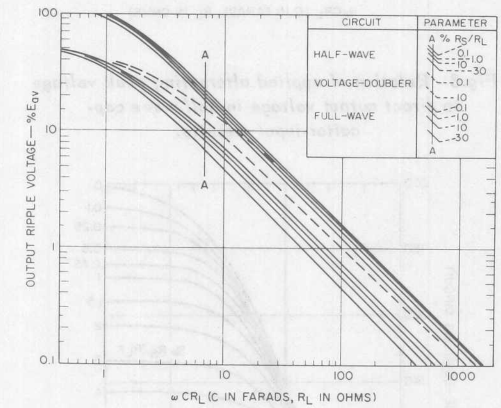


Fig.11 - RMS ripple voltage of capacitor-input circuits.

The following examples illustrate the use of Figs.8 through 11 in rectifier-current calculations. Both exact and approximate solutions are given for each example.

Example No. 3: For the half-wave circuit of Fig. 4, the resistive-to-capacitive reactance is found to be:

$$\omega CR_L = (2\pi)(60)\ (2.5 \times 10^{-6})\ (200{,}000)$$

$$\omega CR_L = 189$$

Exact solution using Fig. 6: The ratio of R_S to R_L must first be calculated as follows:

$$\% \frac{R_S}{R_L} = \frac{150 \times 100\%}{200{,}000} = 0.075\%$$

The values given above are then plotted in Fig. 8 to determine average output voltage and average output current, as follows:

$$E_{avg}/E_o = 98\%$$

$$E_{avg} = (0.98)\ (4950) = 4850 \text{ volts}$$

$$I_{avg} = E_{avg}/R_L$$

$$I_{avg} = 4850/200{,}000 = 24.2 \text{ milliamperes}$$

This value of I_{avg} is then substituted in the ratio of I_{rms}/I_{avg} obtained from Fig. 6, and the exact value of rms current in the rectifier is determined, as follows:

$$I_{rms}/I_{avg} = 4.4$$

$$I_{rms} = (4.4)\ (24.2) = 107 \text{ milliamperes}$$

Simplified solution using Fig. 7: Average output current is approximately equal to peak input voltage divided by load resistance, as given by

$$I_{avg} = E_o/R_L$$

$$I_{avg} = 4950/200{,}000 = 24.7 \text{ milliamperes}$$

This value of I_{avg} is then substituted in the ratio of I_{rms}/I_{avg} obtained from Fig. 7 and the approximate rms current is determined, as follows:

$$I_{rms}/I_{avg} = 5.7$$

$$I_{rms} = (5.7)\ (24.7) = 141 \text{ milliamperes}$$

Example No. 4: For the doubler circuit of Fig. 5, the resistive-to-capacitive reactance is determined as follows:

$$\omega CR_L = (2\pi)\ (60)\ (10^{-5})\ (50{,}000)$$

$$\omega CR_L = 189$$

$$n\,\omega CR_L = 94$$

Exact solution: The ratio of R_S to R_L is determined as follows:

$$\% \frac{R_S}{R_L} = \frac{100 \times 100\%}{50{,}000} = 0.2\%$$

This percentage is then used in conjunction with Fig. 9, and E_{avg} and I_{avg} are determined as follows:

$$E_{avg}/E_o = 186\%$$

$$E_{avg} = (1.86)\ (3820) = 7100 \text{ volts}$$

$$I_{avg} = E_{avg}/R_L$$

$$I_{avg} = 7100/50{,}000 = 142 \text{ milliamperes}$$

The values given above are then plotted in Fig. 6, and the rms current is calculated as follows:

$$I_{rms}/I_{avg} = 3.7$$

$$I_{rms} = (3.7)\ (142) = 525 \text{ milliamperes}$$

Simplified solution: The average output current is given by

$$I_{avg} = 2E_o/R_L$$

$$I_{avg} = (2 \times 3820)/50{,}000 = 153 \text{ milliamperes}$$

This value is then plotted in Fig. 7, and the rms cur- is determined as follows:

$$I_{rms}/I_{avg} = 4.8$$

$$I_{rms} = (4.8)\ (153) = 734 \text{ milliamperes}$$

As previously noted, the simplified solution in both examples predicted a higher rms current than the actual value: about 32 per cent higher in Example No. 3 and 40 per cent higher in Example No. 4. The amount of error involved depends on both ωCR_L and R_S/R_L.

Rating Curves for RMS Current Versus Temperature

In most technical data for rectifiers, the current-versus-temperature ratings are given in terms of average current for a resistive load with 60-Hz sinusoidal input voltage. However, when the ratio of peak-to-average current becomes higher (as with capacitive loads), junction heating effects become more and more dependent on rms current rather than average current. Therefore, the capacitive-load ratings should be obtained from a curve of rms current as a function of temperature. The average current-rating curves for a sinusoidal source and resistive load may be converted to rms-rating curves simply by multiplying the current axis by 1.57 because this value is the ratio of rms-to-average current for such service (as shown by I_{rms}/I_{avg} at low ωCR_L in Figs. 6 and 7). An example of this conversion is shown in Fig. 12 for the rating curves of seven stack rectifiers.

The following examples illustrate the use of the rms current ratings.

Example No. 5: For the half-wave circuit of Fig. 4, it was found in Example No. 3 that the actual rms current in the rectifier is 107 milliamperes. The rms rating curve in Fig. 12 shows that the CR7 may carry up to 107 milliamperes at ambient temperatures up to 115°C.

Example No. 6: For the doubler circuit of Fig. 5, the actual rms current was determined to be 525 milliamperes. The rms rating curve for the CR6 in Fig. 12 shows that the circuit may be operated up to 88° C ambient temperature.

Example No. 7: If the higher values of rms current given by the simplified solution are used instead of the actual currents, the rms rating curves of Fig. 12 also give more conservative ratings because they predict a lower value for the maximum permissible ambient temperature. For example, for the half-wave circuit the exact rms current was found to be 107 milliamperes, and the approximate value was 141 milliamperes. These current values correspond to a maximum ambient temperature rating of 115°C by the exact solution and 110°C by the approximate solution.

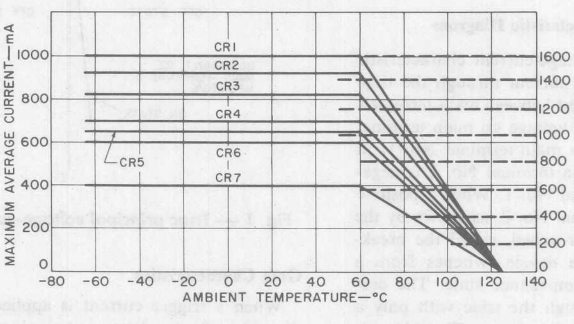


Fig. 12 - Current as a function of temperature for silicon rectifier stacks.

TRIAC POWER-CONTROL APPLICATIONS

by
J. V. YONUSHKA

In the control of ac power by means of semiconductor devices, emphasis has been placed upon limiting the complexity of the circuits involved, the cost of the system, and the over-all package size. With the development of the bidirectional triode thyristor, commonly known as the triac, all of these goals can be achieved. A triac can perform the functions of two SCR's for full-wave operation and can easily be triggered in either direction to simplify gate circuits. Because they are rated for 120-volt and 240-volt line operation, triacs are readily adaptable for the control of power to any equipment being operated directly from ac power lines. When used for ac power control, triacs add new functions to many designs, improve performance, and provide maximum efficiency and high reliability. This Note describes triac operating characteristics and provides guidance in the use of triacs for specific applications.

Principal Voltage-Current Characteristic Diagram

Fig. 1 shows the principal voltage-current characteristic of a triac. This curve shows the current through the triac as a function of the voltage applied between main terminals Nos. 1 and 2. In quadrant I, the voltage on main terminal No. 2 is positive with respect to main terminal No. 1; in quadrant III, the voltage on main terminal No. 2 is negative with respect to main terminal No. 1. When a positive voltage is applied to main terminal No. 2, as shown by the curve in quadrant I, a point is reached, called the breakover voltage V_{BO}, at which the device switches from a high-impedance state to a low-impedance state. The current can then be increased through the triac with only a small increase in voltage across the device. The triac remains in the ON state until the current through the main terminals drops below a value, called the holding current, which cannot maintain the breakover condition. The triac then reverts again to the high-impedance or OFF state. If the voltage across the main terminals of the triac is reversed, the same switching action occurs as shown by the curve in quadrant III. Thus, the triac is capable of switching from the OFF state to the ON state for either polarity of voltage applied to the main terminals.

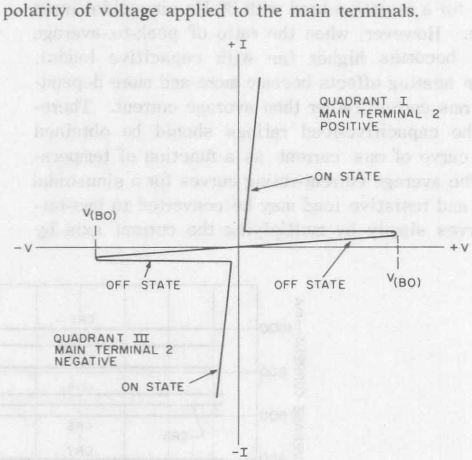


Fig. 1 — Triac principal voltage-current characteristics.

Gate Characteristics

When a trigger current is applied to the gate terminal of a triac, the breakover voltage is reduced. After the triac is triggered, the current flow through the main terminals is independent of the gate signal and the triac remains in the ON state until the principal current is reduced below the

holding-current level. The triac has the unique capability of being triggered by either a positive or a negative gate signal regardless of the voltage polarity across the main terminals of the device. Fig. 2 illustrates the triggering mechanism and current flow within a triac. The gate trigger polarity is always referenced to main terminal No. 1. The potential difference between the two terminals is such that gate current flows in the direction indicated by the dotted arrow. The polarity symbol at main terminal No. 2 is also referenced to main terminal No. 1. The semiconductor materials between the various junctions within the pellet are labeled p and n to indicate the type of majority-carrier concentrations within the material.

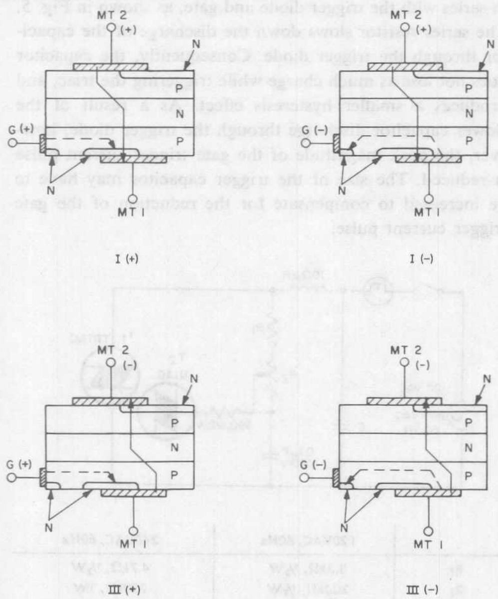


Fig. 2 – Current flow in a triac.

For the various operating modes, the polarity of the voltage on main terminal No. 2 with respect to main terminal No. 1 is given by the quadrant in which the triac operates, (either I or III) and the polarity of the gate signal used to trigger the device is given by the proper symbol next to the operating quadrant. For the I (+) operating mode, therefore, main terminal No. 2 and the gate are both positive with respect to main terminal No. 1. Initial gate current flows into the gate terminal, through the p-type layer, across the junction into the n-type layer, and out main terminal No. 1, as shown by the dotted arrow. As gate current flows, current multiplication occurs and the regenerative action within the pellet switches the triac to its ON state. Because of the polarities indicated between the main terminals, the principal current flows through the pnpn structure as shown by the solid arrow. Similarly, for the other three operating modes, the initial gate current flow is shown by the dotted arrow, and principal current flow through the main terminals is shown by the solid arrow.

Because the principal current influences the gate trigger current, the magnitude of the current required to trigger the triac differs for each mode. The operating modes in which the principal current is in the same direction as the gate current require less gate trigger current, while modes in which the principal current is in opposition to the gate current require more gate trigger current.

Like many other semiconductor parameters, the magnitude of the gate trigger current and voltage varies with the junction temperature. As the thermal excitation of carriers within the semiconductor increases, the increase in leakage current makes it easier for the device to be triggered by a gate signal. Therefore, the gate becomes more sensitive in all operating modes as the junction temperature increases. Conversely, if the triac is to be operated at low temperatures, sufficient gate trigger current must be provided to assure triggering of all devices at the lowest operating temperature expected in any particular application. Variations of gate trigger requirements are given in the data sheets for individual triacs.

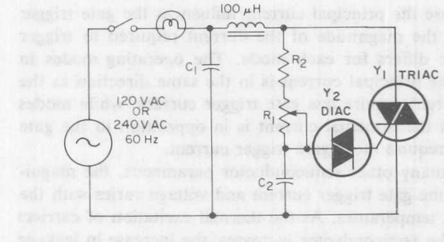
Light Control

Because the light output of an incandescent lamp depends upon the voltage impressed upon the lamp filament, changes in the lamp voltage vary the brightness of the lamp. When ac source voltages are used, a triac can be used in series with an incandescent lamp to vary the voltage to the lamp by changing its conduction angle; i.e., the portion of each half cycle of ac line voltage in which the triac conducts to provide voltage to the lamp filament. The triac, therefore, is very attractive as a switching element in light-dimming applications.

To switch incandescent-lamp loads reliably, a triac must be able to withstand the inrush current of the lamp load. The inrush current is a result of the difference between the cold and hot resistance of the tungsten filament. The cold resistance of the tungsten filament is much lower than the hot resistance. The resulting inrush current is approximately 12 times the normal operating current of the lamp.

The simplest circuit that can be used for light-dimming applications is shown in Fig. 3 and uses a trigger diode in series with the gate of a triac to minimize the variations in gate trigger characteristics. Changes in the resistance in series with the capacitor change the conduction angle of the triac.

The capacitor in the circuit of Fig. 3 is charged through the control potentiometer and the series resistance. The series resistance is used to protect the potentiometer potentiometer is at its minimum resistance setting. This resistor may be eliminated if the potentiometer can withstand the peak charging current until the triac turns on. The trigger diode conducts when the voltage on the capacitor reaches the diode breakover voltage. The capacitor then discharges through the trigger diode to produce a current pusle of sufficient amplitude and width to trigger the triac. Because the triac can be triggered with either



	120VAC, 60Hz	240VAC, 60Hz
R_1	200kΩ, ½W	250kΩ, 1W
R_2	3.3kΩ, ½W	4.7kΩ, ½W
C_1	0.1μF, 200V	0.1μF, 400V
C_2	0.1μF, 100V	0.1μF, 100V
Y_1	T2800B	T2800D
Y_2	D3202U	D3202U

Fig. 3 – Single-time-constant light-dimmer circuit.

polarity of gate signal, the same operation occurs on the opposite half-cycle of the applied voltage. The triac, therefore, is triggered and conducts on each half-cycle of the input supply voltage.

The interaction of the RC network and the trigger diode results in a hysteresis effect when the triac is initially triggered at small conduction angles. The hysteresis effect is characterized by a difference in the control potentiometer setting when the triac is first triggered and when the circuit turns off. Fig. 4 shows the interaction between the RC network and the trigger diode to produce the hysteresis effect. The capacitor voltage and the ac line voltage are shown as solid lines. As the resistance in the circuit is decreased from its maximum value, the capacitor voltage reaches a value which fires the trigger diode. This point is designated A on the capacitor-voltage wave-shape. When the trigger diode fires, the capacitor discharges and triggers the triac at an initial conduction angle θ_1. During the forming of the gate trigger pulse, the capacitor voltage drops suddenly. The charge on the capacitor is smaller than when the trigger diode did not conduct. As a result of the different voltage conditions on the capacitor, the breakover voltage of the trigger diode is reached earlier in the next half-cycle. This point is labeled point B on the capacitor-voltage waveform. The conduction angle θ_2, corresponding to point B is greater than θ_1. All succeeding conduction angles

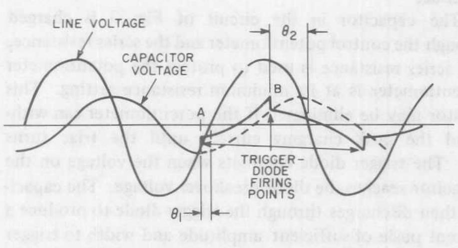
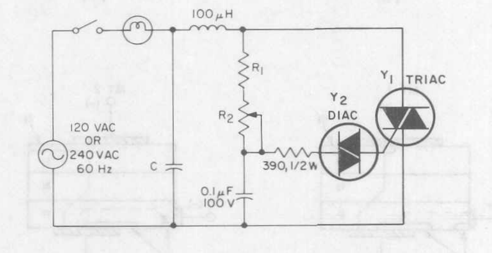


Fig. 4 – Waveforms showing interaction of control network and trigger diode.

are equal to θ_2 in magnitude. When the circuit resistance is increased by a change in the potentiometer setting the triac is still triggered, but at a smaller conduction angle. Eventually, the resistance in series with the capacitance becomes so great that the voltage on the capacitor does not reach the breakover voltage of the trigger diode. The circuit then turns off and does not turn on until the circuit resistance is again reduced to allow the trigger diode to be fired. The hysteresis effect makes the voltage load appear much greater than would normally be expected when the circuit is initially turned on.

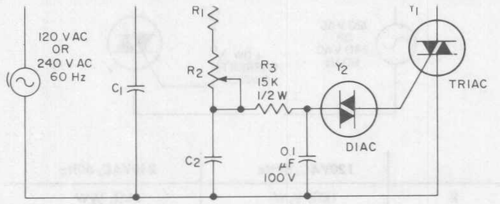
The hysteresis effect can be reduced by use of a resistor in series with the trigger diode and gate, as shown in Fig. 5. The series resistor slows down the discharge of the capacitor through the trigger diode. Consequently, the capacitor does not lose as much charge while triggering the triac, and produces a smaller hysteresis effect. As a result of the slower capacitor discharge through the trigger diode, however, the peak magnitude of the gate trigger current pulse is reduced. The size of the trigger capacitor may have to be increased to compensate for the reduction of the gate trigger current pulse.



	120VAC, 60Hz	240VAC, 60Hz
R_1	3.3kΩ, ½W	4.7kΩ, ½W
R_2	200kΩ, ½W	250kΩ, 1W
C	0.1μF, 200V	0.1μF, 400V
Y_1	T2800B	T2800D
Y_2	D3202U	D3202U

Fig. 5 – Single-time-constant light-dimmer circuit with series gate resistor.

The double-time-constant circuit in Fig. 6 improves on the performance of the single-time-constant control circuit. This circuit uses an additional RC network to extend the phase angle so that the triac can be triggered at small conduction angles. The additional RC network also minimizes the hysteresis effect. Fig. 7 shows the voltage waveforms for the ac supply and the trigger capacitor of the circuit of Fig. 6. Because of the voltage drop across R_3, the input capacitor C_2 charges to a higher voltage than the trigger capacitor C_3. When the voltage on C_3 reaches the breakover voltage of the trigger diode, the diode conducts and causes the capacitor to discharge and produce the gate current pulse to trigger the triac. After the trigger diode turns off, the charge on C_3 is partially restored by



	120VAC, 60Hz	240VAC, 60Hz
R_1	2.2kΩ, ½W	3.3kΩ, ½W
R_2	100kΩ, ½W	200kΩ, 1W
C_1 C_2	0.1μF, 200V	0.1μF, 400V
Y_1	T2800B	T2800D
Y_2	D3202U	D3202U

Fig. 6 — Double-time-constant light-dimmer circuit.

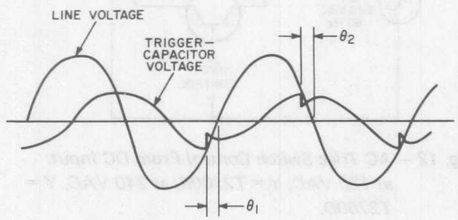
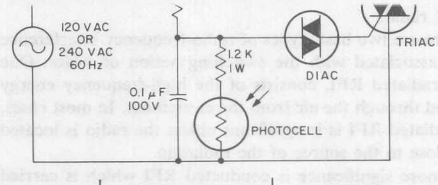


Fig. 7 — Voltage waveforms of double-time-constant control circuit.

the charge from the input capacitor C_2. The partial restoration of charge on C_3 results in better circuit performance with a minimum of hysteresis.

Light-Activated Control

For applications requiring a light-activated circuit, such as outdoor lights or indoor night lights, the circuit shown in Fig. 8 can be employed. Although this circuit functions in the same manner as the light-dimming circuit, the photocell controls its operation. When the light impinges on the surface of the photocell, the resistance of the photocell becomes low and prevents the voltage on the trigger capacitor from increasing to the breakover voltage of the trigger diode. The circuit is then inoperative. When the light source is removed, the photocell becomes a high resistance. The voltage on the trigger capacitor then increases to the breakover voltage of the trigger diode and causes the diode to fire. The trigger pulse formed by the capacitor discharge through the trigger diode makes the triac conduct and operates the circuit. The triac continues to be triggered on each half-cycle and supplies power to the load as long as the resistance of the photocell is high. When light again impinges on the surface of the photocell

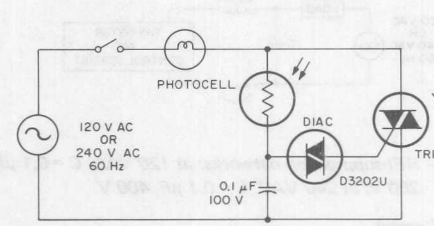


	120VAC, 60Hz	240VAC, 60Hz
R	15kΩ, 2W	30kΩ, 3W
Y	T2800B	T2800D

Fig. 8 — Light Controlled Turn-Off Circuit.

and reduces its resistance, the voltage on the capacitor can no longer reach the breakover voltage of the trigger diode, and the circuit turns off.

For applications requiring operation when light impinges on the surface of the photocell, the circuit of Fig. 9 is recommended. In this circuit, low resistance of the photocell allows the triac to be triggered on. When light is removed from the photocell the increased resistance of the photocell prevents the triac from being triggered and renders the circuit inoperative.



	120VAC, 60Hz	240VAC, 60Hz
Y	T2800B	T2800D

Fig. 9 — Light Controlled Turn-On Circuit.

Radio Frequency Interference

The fast switching action of triacs when they turn on into resistive loads causes the current to rise to the instantaneous value determined by the load in a very short period of time. This fast switching action produces a current step which is largely composed of higher-harmonic frequencies that have an amplitude varying inversely as the frequency. In phase-control applications, such as light dimming, this current step is produced on each half-cycle of the input voltage. Because the switching occurs many times a second, a noise pulse is generated into frequency-sensitive devices

such as AM radios and causes annoying interference. The amplitude of the higher frequencies in the current step is of such low levels that they do not interfere with television or FM radio.

There are two basic types of radio-frequency interference (RFI) associated with the switching action of triacs. One form, radiated RFI, consists of the high-frequency energy radiated through the air from the equipment. In most cases, this radiated RFI is insignificant unless the radio is located very close to the source of the radiation.

Of more significance is conducted RFI which is carried through the power lines and affects equipment attached to the same power lines. Because the composition of the current waveshape consists of higher frequencies, a simple choke placed in series with the load slows down the current rise time and reduces the amplitude of the higher harmonics. To be effective, however, such a choke must be quite large. A more effective filter, and one that has been found adequate for most light-dimming applications is shown in Fig. 10. The LC filter provides adequate attenuation of the high-frequency harmonics and reduces the noise interference to a low level.

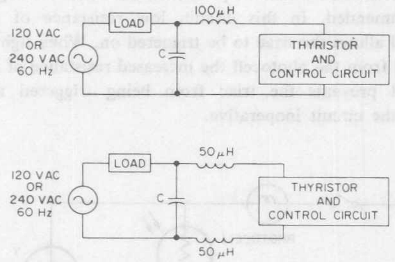


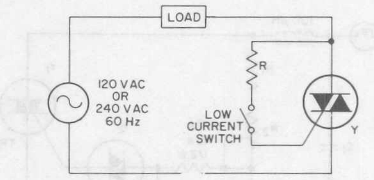
Fig. 10 – RFI-suppression networks: at 120 VAC, C = 0.1 μF, 200 V; at 240 VAC, C = 0.1 μF, 400 V.

Motor Control

Triacs can be used very effectively to apply power to motors and perform such functions as speed control, reversing, full power switching, or any other desired operating condition that can be obtained by a switching action. Because most motors are line-operated, the triac can be used as a direct replacement for electro-mechanical switches. In proper control circuits, triacs can change the operating characteristics of motors to obtain many different speed and torque curves.

A very simple triac static switch for control of ac motors is shown in Fig. 11. The low-current switch controlling the gate trigger current can be any type of transducer, such as a pressure switch, a thermal switch, a photocell, or a magnetic reed relay. This simple type of circuit allows the motor to be switched directly from the transducer switch without any intermediate power switch or relay.

For dc control, the circuit of Fig. 12 can be used. By use of the dc triggering modes, the triac can be directly triggered from transistor circuits by either a pulse or continuous signal.



	120VAC, 60Hz	240VAC, 60Hz
R	1kΩ, ½W	2kΩ, ½W
Y	T2700B	T2700D

Fig. 11 – Simple Triac Static Switch.

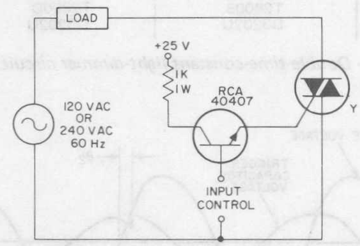
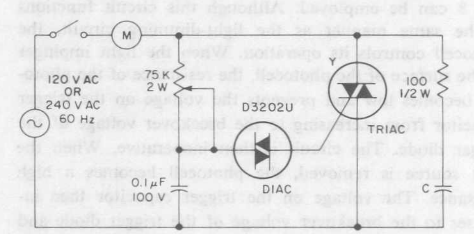


Fig. 12 – AC Triac Switch Control From DC Input: at 120 VAC, Y = T2700B; at 240 VAC, Y = T2700D.

Induction Motor Controls

Fig. 13 shows a single-time-constant circuit which can be used as a satisfactory proportional speed control for some applications and with certain types of induction motors, such as shaded pole or permanent split-capacitor motors, when the load is fixed. This type of circuit is best suited to applications which require speed control in the medium to full-power range. It is specifically useful in applications such as fans or blower-motor controls, where a small change in motor speed produces a large change in



	120VAC, 60Hz	240VAC, 60Hz
C	0.22μF, 200V	0.22μF, 400V
Y	T2700B	T2700D

Fig. 13 – Induction motor control.

air velocity. Caution must be exercised if this type of circuit is used with induction motors because the motor may stall suddenly if the speed of the motor is reduced below the drop-out speed for the specific operating condition determined by the conduction angle of the triac. Because the single-time-constant circuit cannot provide speed control of an induction motor load from maximum power to full off, but only down to some fraction of the full-power speed, the effects of hysteresis described previously are not present. Speed ratios as high as 3:1 can be obtained from the single-time-constant circuit used with certain types of induction motors.

Because motors are basically inductive loads and because the triac turns off when the current reduces to zero, the phase difference between the applied voltage and the device current causes the triac to turn off when the source voltage is at a value other than zero. When the triac turns off, the instantaneous value of input voltage is applied directly to the main terminals of the triac. This commutating voltage may have a rate of rise which can retrigger the triac. The commutating dv/dt can be limited to the capability of the triac by use of an RC network across the device, as shown in Fig. 13. The current and voltage waveshapes for the circuit are shown in Fig. 14 to illustrate the principle of commutating dv/dt.

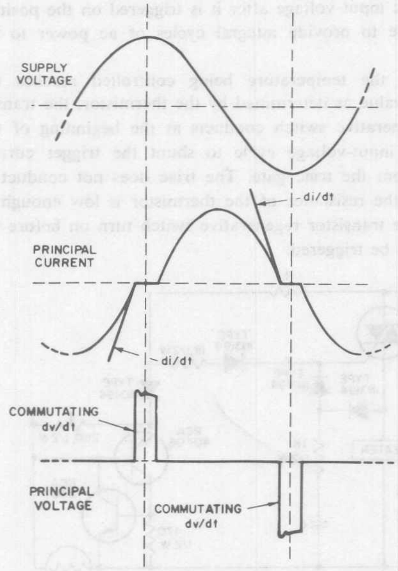
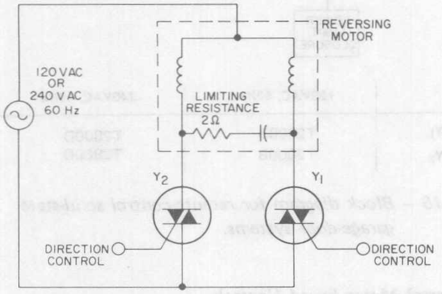


Fig. 14 – Waveshapes of commutating dv/dt characteristics.

Reversing Motor Control

In many industrial applications, it is necessary to reverse the direction of a motor, either manually or by means of an auxiliary circuit. Fig. 15 shows a circuit which uses two triacs to provide this type of reversing motor control. The reversing switch can be either a manual switch or an electronic switch used with some type of sensor to reverse the direction of the motor. A resistance is added in series with the capacitor to limit capacitor discharge current to a safe value whenever both triacs are conducting simultaneously. Simultaneous conduction can easily occur because the triggered triac remains in conduction after the gate is disconnected until the current reduces to zero. In the meantime, the nonconducting-triac gate circuit can be energized so that both triacs are ON and large loop currents are set up in the triacs by the discharge of the capacitor.

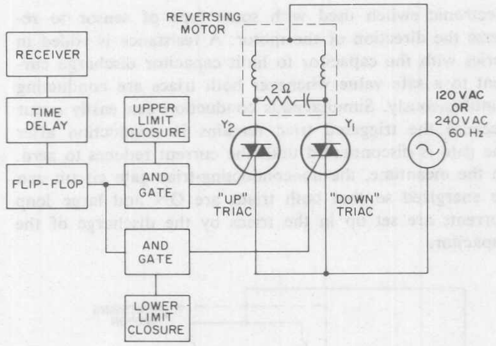


	120VAC, 60Hz	*240VAC, 60Hz*
Y_1	T2800B	T2800D
Y_2	T2800B	T2800D

Fig. 15 – Reversing motor control.

Electronic Garage-Door System

The triac motor-reversing circuit can be extended to electronic garage-door systems which use the principle of motor reversing for garage-door direction control. The system contains a transmitter, a receiver, and an operator to provide remote control for door opening and closing. The block diagram in Fig. 16 shows the functions required for a complete solid-state system. When the garage door is closed, the gate drive to the DOWN triac is disabled by the lower-limit closure and the gate drive to the UP triac is inactive because of the state of the flip-flop. If the transmitter is momentarily keyed, the receiver activates the time-delay monostable multivibrator so that it then changes the flip-flop state and provides continuous gate drive to the UP triac. The door then continues to travel in the UP direction until the upper-limit switch closure disables gate drive to the UP triac. A second keying of the transmitter provides the DOWN triac with gate drive and causes the door to travel in the DOWN direction until the gate drive is disabled by the lower limit closure. The time in which the monostable multivibrator is active should override normal transmitter keying for the purpose of eliminating erroneous firing. A feature of this system is that, during travel, transmitter keying provides motor reversing independent of the upper- or lower-limit closures. Additional features, such as obstacle obstructions, manual control, or time delay for overhead garage lights can be achieved very economically.

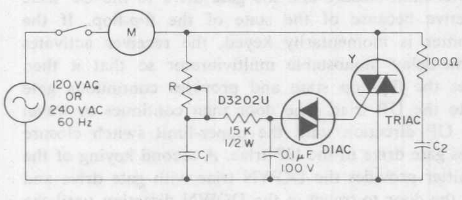


	120VAC, 60Hz	240VAC, 60Hz
Y_1	T2800B	T2800D
Y_2	T2800B	T2800D

Fig. 16 – Block diagram for remote-control solid-state garage-door systems.

Universal Motor Speed Controls

In applications in which the hysteresis effect can be tolerated or which require speed control primarily in the medium to full-power range, a single-time-constant circuit such as that shown in Fig. 13 for induction motors can also be used for universal motors. However, it is usually desirable to extend the range of speed control from full-power ON to very low conduction angles. The double-time-constant circuit shown in Fig. 17 provides the delay necessary to trigger the triac at very low conduction angles with a minimum of hysteresis, and also provides practically full power to the load at the minimum-resistance position of the control potentiometer. When this type of control circuit is used, an infinite range of motor speeds can be obtained from very low to full-power speeds.



	120VAC, 60Hz	240VAC, 60Hz
R	100kΩ, ½ W	200kΩ, 1W
C_1	0.1μF, 200V	0.1μF, 400V
C_2	0.22μF, 200V	0.22μF, 400V
Y	T2700B	T2700D

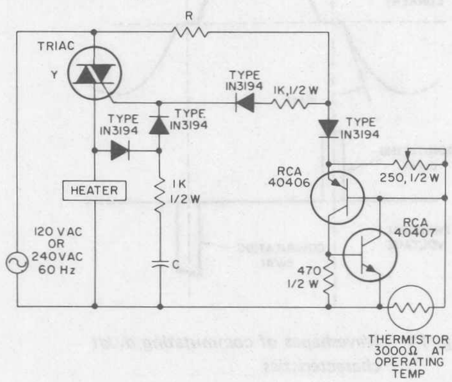
Fig. 17 – Universal Motor Speed Control.

Heat Control

There are three general categories of solid-state control circuits for electric heating elements: on-off control, phase control, and porportional control using integral-cycle synchronous switching. Phase-control circuits, such as those used for light dimming are very effective and efficient for electric heat control except for the problem of RFI. In higher-power applications, the RFI is of such magnitude that suppression circuits to minimize the interference become quite bulky and expensive.

An on-off circuit for the control of resistance-heating elements is shown in Fig. 18. The circuit also provides synchronous switching close to the beginning of the zero-voltage crossing of the input voltage to minimize RFI. The thermistor controls the operation of the two-transistor regenerative switch, which, in turn, controls the operation of the triac. When the temperature being controlled is low, the resistance of the thermistor is high and the regenerative switch is OFF. The triac is then triggered directly from the line on positive half-cycles of the input voltage. When the triac triggers and applies voltage to the load, the capacitor is charged to the peak value of the input voltage. The capacitor discharges through the triac gate to trigger the triac on the opposite half-cycle. The diode-resistor-capacitor "slaving" network triggers the triac on negative half-cycles of the ac input voltage after it is triggered on the positive half-cycle to provide integral cycles of ac power to the load.

When the temperature being controlled reaches the desired value as determined by the thermistor, the transistor regenerative switch conducts at the beginning of the positive input-voltage cycle to shunt the trigger current away from the triac gate. The triac does not conduct as long as the resistance of the thermistor is low enough to make the transistor regenerative switch turn on before the triac can be triggered.



	120VAC, 60Hz	240VAC, 60Hz
R	2.2kΩ, 5W	3.9kΩ, 5W
C	0.5μF, 200V	0.5μF, 400V
Y	T4700B	T4700D

Fig. 18 – Synchronous switching on-off heat controller.

Proportional Integral-Cycle Control

On-off controls have only two levels of power input to the load. The heating coils are either energized to full power or are at zero power. Because of thermal time constants, on-off controls produce a cyclic action which alternates between thermal overshoots and undershoots with poor resolution.

This disadvantage is overcome and RFI is minimized by use of the concept of integral-cycle proportional control with synchronous switching. In this system, a time base is selected and the on-time of the triac is varied within the time base. The ratio of the on-to-off time of the triac within this time interval depends upon the power required to the heating elements to maintain the desired temperature. Fig. 19 shows the on-off ratio of the triac. Within the time period, the on-time varies by an integral number of cycles from full ON to a single cycle of input voltage.

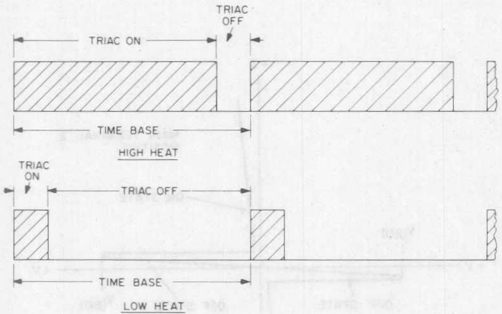


Fig. 19 – Triac duty cycle.

One method of achieving integral cycle proportional control is to use a fixed-frequency sawtooth generator signal which is summed with a dc control signal. The sawtooth generator establishes the period or time base of the system. The dc control signal is obtained from the output of the temperature-sensing network. The principle is illustrated in Fig. 20. As the sawtooth voltage increases, a level is reached which turns on power to the heating elements. As the temperature at the sensor changes, the dc level shifts accordingly and changes the length of time that the power is applied to the heating elements within the established time.

When the demand for heat is high, the dc control signal is high and little power is supplied continuously to the heating elements. When the demand for heat is completely satisfied, the dc control signal is low and no power is supplied to the heating elements. Usually a system using this principle operates continuously somewhere between full ON and full OFF to satisfy the demand for heat.

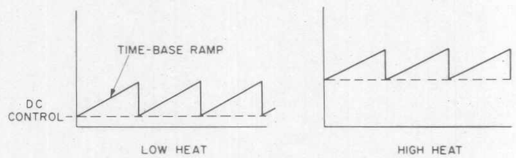
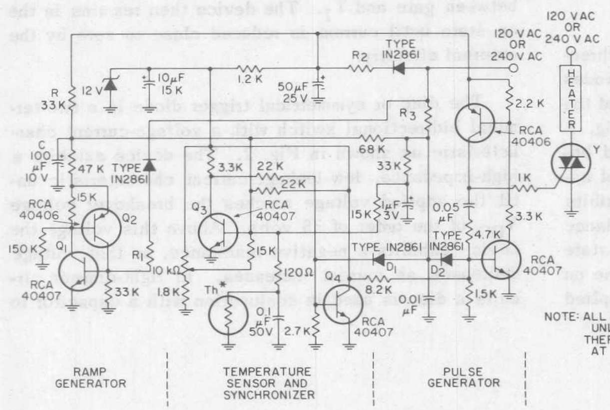


Fig. 20 – Proportional-controller waveshapes.

A proportional integral-cycle heat control system is shown in Fig. 21. The ramp voltage is generated by charging of capacitor C through resistor R for approximately 2 seconds for the values shown. The length of the ramp is determined by the voltage magnitude required to trigger the regenerative switch consisting of Q_1 and Q_2. The temperature sensor consisting of Q_3 and Q_4, together with the controlling thermistor Th, establishes a voltage level at the base of Q_3 which depends upon the resistance value of the thermistor. Q_3 and Q_4 form a bistable multivibrator. The state of the multivibrator depends upon the base bias of Q_3. When Q_3 is conducting, Q_4 is cut off. The pulse generator is energized and generates pulses to trigger the triac. The output of the pulse generator is synchronized to the line voltage on the negative half-cycle by D_2 and R_3 and on the positive half-cycle by D_1 and R_3. The pulses are, therefore, generated at the zero-voltage crossings and trigger the triacs into conduction at only these points.



	120VAC, 60Hz	240VAC, 60Hz
R_1	60kΩ, ½W	120kΩ, ½W
R_2	3.3kΩ, 2W	5.6kΩ, 2W
R_3	33kΩ, ½W	57kΩ, ½W
Y	2N5441 or 2N5444	2N5442 or 2N5445

NOTE: ALL RESISTORS 1/2 W, ±10% UNLESS OTHERWISE SPECIF. THERMISTOR APPROX. 3000 Ω AT OPERATING TEMP.

Fig. 21 – Proportional integral-cycle heat controller.

Light Dimmers Using Triacs

by J. M. Neilson

Introduction

A simple, inexpensive light-dimmer circuit contains a diac, triac and RC charge-control network. The diac is a two-terminal ac switch which is changed from the non-conducting state to the conducting state by an appropriate voltage of either polarity. The triac is a three-terminal ac switch which is changed from the non-conducting state to the conducting state when a positive or negative voltage is applied to the gate terminal. This Note describes the use of the diac to trigger the triac in light-dimming circuits. The basic light-control circuit is introduced and its operation described. In addition, the various components added to improve circuit performance are discussed. Three complete circuits are shown, with tables showing the component values to be used for 120-volt, 60-Hz operation and 240-volt, 50/60 Hz operation. Mechanical details involved in building the circuits are also discussed and a trouble-shooting chart is included.

Circuit Description

The triac or bidirectional triode thyristor is a three-terminal solid-state switch. The two power electrodes or main terminals are referred to as T_1 and T_2, and the control electrode is referred to as the gate. Fig. 1 shows the voltage-current characteristic observed between the power electrodes. For either polarity of applied voltage, the device is bistable: the triac exhibits either a high impedance (off state) or a low impedance (on state). The device normally assumes the off state when bias is applied, but can be triggered into the on state by a pulse of current, of either polarity, applied between gate and T_1. The device then remains in the on state until current is reduced close to zero by the external circuitry.

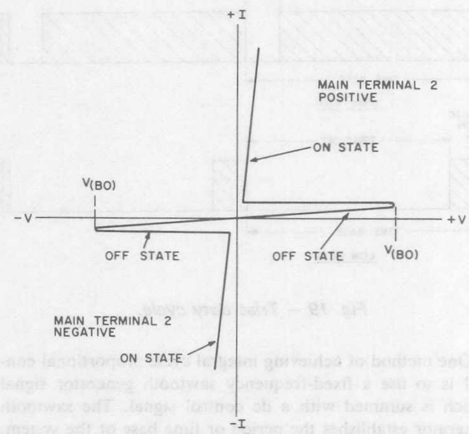


Fig.1 - Voltage-current characteristic of a triac.

The diac or symmetrical trigger diode is a two-terminal bidirectional switch with a voltage-current characteristic as shown in Fig. 2. The device exhibits a high-impedance, low-leakage-current characteristic until the applied voltage reaches the breakover voltage V_{BO}, of the order of 35 volts. Above this voltage the device exhibits a negative resistance, so that voltage decreases as current increases. In light-dimmer circuits a diac is used in conjunction with a capacitor to

generate current pulses which trigger the triac into conduction. The voltage on the diac and capacitor increases until it reaches V_{BO}, at which point the diac voltage breaks back and a pulse of current flows as the capacitor discharges.

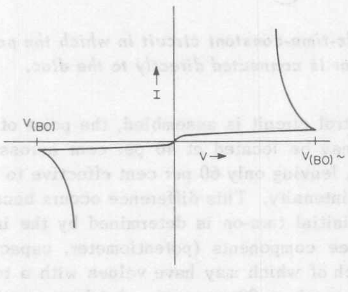


Fig.2 - Voltage-current characteristic of a diac.

Fig. 3 shows the basic triac-diac light control circuit with the triac connected in a series with the load. During the beginning of each half cycle the triac is in the off-state. As a result, the entire line voltage appears across the triac, and none appears across the load. Because the triac is in parallel with the potentiometer and capacitor, the voltage across the triac drives current through the potentiometer and charges the capacitor. When the capacitor voltage reaches the breakover voltage V_{BO} of the diac, the capacitor discharges through the triac gate, turning on the triac. At this point, the line voltage is transferred from the triac to the load for the remainder of that half cycle. This sequence of events is repeated for every half cycle of either polarity. If the potentiometer resistance is reduced, the capacitor charges more rapidly and V_{BO} is reached earlier in the cycle, increasing the power applied to the load and hence the intensity of light. If the potentiometer resistance is increased, triggering occurs later, load power is reduced, and the light intensity is decreased.

Although the basic light-control circuit operates with the component arrangement shown in Fig. 3, additional components and sections are usually added to reduce hysteresis effects, extend the effective range of the light-control potentiometer, and suppress radio-frequency interference.

Hysteresis

As applied to light controls, the term hysteresis refers to a difference in the control potentiometer setting at which the light initially turns-on and the setting at which it is extinguished. With high hysteresis, the control may have to be turned across 35 per cent of its range before the light turns on at all, after which the

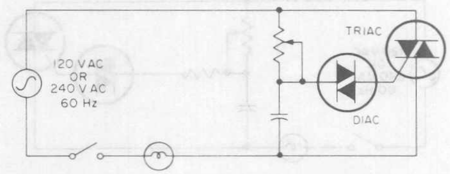


Fig.3 - Basic triac-diac light-control circuit.

control must be turned back to a much lower setting before the light goes completely out.

Besides poor control, hysteresis is undesirable because at low illumination levels, the light may be extinguished by a momentary drop in line voltage. At low illumination levels, the potentiometer is normally turned back beyond the setting at which it initially turned on. When triggering is missed on one half cycle as a result of a momentary drop in line voltage such as that caused by starting a heavy appliance, oil burner, etc., the light may go out and stay out until the control is again turned up to the starting point.

Hysteresis is caused by an abrupt decrease in capacitor voltage when triggering begins. Fig. 4 shows the charging cycle of the capacitor-diac circuit. The large ac sine wave represents the line voltage; the smaller ac sine wave represents the normal charging cycle of the capacitor. Gate triggering occurs at the first point of intersection of the two waves. At this point, however, there is an abrupt decrease in the capacitor voltage (dashed line). As a result, the capacitor begins to charge during the next half cycle at a lower voltage and reaches the trigger voltage in the opposite direction earlier in the cycle (2nd (Actual) Gate Trigger Point). Hysteresis is reduced by maintaining some voltage on the capacitor during gate triggering.

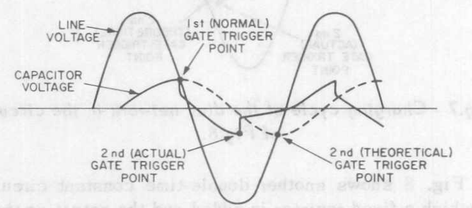


Fig.4 - Charging cycle of the capacitor-diac network in the circuit of Fig.3.

Some improvement is realized when a resistor is connected in series with the diac, as shown in Fig. 5. Although this positive resistance reduces the net amount of negative resistance so the capacitor voltage does not drop as much, it also decreases the magnitude

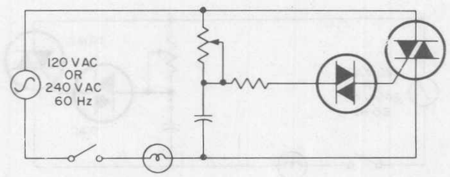


Fig.5 - Light-control circuit incorporating a resistor in series with the diac.

of the gate current pulse, and therefore, a larger-value capacitor may be required. More significant improvement is obtained when a second capacitor is added as shown in Fig. 6, forming a "double-time-constant" circuit.

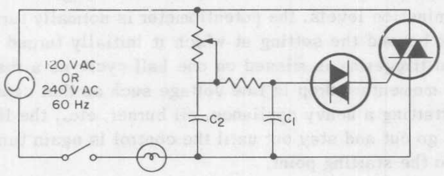


Fig.6 - "Double-time-constant" light-control circuit.

The added capacitor C_2 reduces hysteresis by charging to a higher voltage than C_1, and maintaining some voltage on C_1 after triggering. The effect is illustrated in Fig. 7. As gate triggering occurs C_1 discharges to form the gate current pulse. However, because of the longer C_2 R time constant, C_2 restores some of the charge removed from C_1 by the gate current pulse.

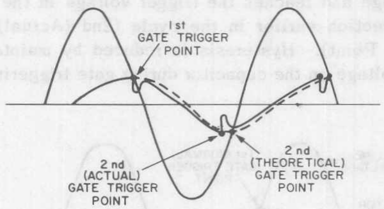


Fig.7 - Charging cycle of the diac network in the circuit of Fig.6.

Fig. 8 shows another double-time constant circuit in which a fixed resistor is added and the potentiometer is moved over to connect directly to the diac. Although the maximum attainable conduction angle is increased, the difference in power is less than one per cent.

Range Control

Maximum range of light control is obtained when the lamp begins to light as soon as the potentiometer is turned slightly from the zero-intensity end of the range.

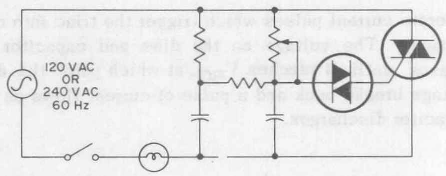


Fig.8 - Double-time-constant circuit in which the potentiometer is connected directly to the diac.

After the control circuit is assembled, the point of initial turn-on may be located at 40 per cent across the control range, leaving only 60 per cent effective to control the light intensity. This difference occurs because the point of initial turn-on is determined by the interaction of three components (potentiometer, capacitor, and diac) each of which may have values with a tolerance of plus or minus 20 per cent. A trimmer resistor connected across the potentiometer, as shown in Fig. 9, can be used to compensate for component variations and move the initial turn-on point back to the end of the control range. The trimmer can be a variable resistor which is set to the required value after the circuit is assembled, or a fixed resistor of the required value as determined by individually testing the assemblies with a resistor substitution box in place of the trimmer.

The double-time-constant circuit with trimmer resistor provides consistently good hysteresis correction as well as good range control. The use of a high-resistance potentiometer, possibly about twice the resistance of the trimmer, spreads out the low-intensity range for finer control.

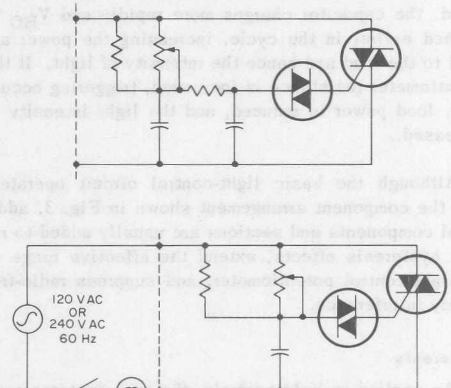


Fig.9 - Light-control circuits incorporating a trimmer resistor across the potentiometer.

state to the low-impedance state within 1 or 2 microseconds, the current must rise from essentially zero to whatever the load will permit within this period. This rapid rise in current produces radio frequency interference (RFI) extending up into the range of several megahertz. Although the resulting noise does not affect the television and FM radio frequencies, it does affect the short-wave and AM-radio bands. The level of RFI produced by the triac is well below that produced by most AC-DC brush-type electric motors, but because the light dimmer may be on for long periods of time, some type of RFI suppression network is usually added. A reasonably effective suppression network is obtained, as

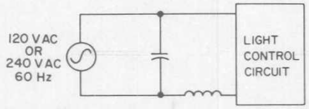


Fig.10 - RFI-suppression network.

shown in Fig. 10, by connection of an inductor in series with the light-control circuit to limit the rate of current rise. The capacitor is connected across the entire network to bypass high-frequency signals so that they are not connected to any external circuits through the power lines.

Overload Considerations

An important consideration in the choice of a triac is the transient load which results from the initially lower resistance of the cold filament when the lamp is first turned on. The transient load results in a surge or inrush current which can destroy the triac. The worst case occurs when the light is switched on at the peak of the line voltage. The ratio of initial peak current to steady-state current is usually about 10 to 1 and can be as high as 15 to 1 for high-wattage lamps. The triac chosen for a particular lamp, therefore, should have a subcycle surge capability sufficient to allow repeated passage of this peak current without degradation of the device.

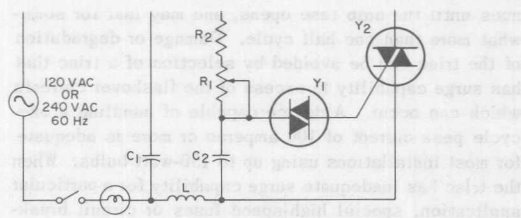
Flashover is another transient condition associated with incandescent loads, and may impose an even greater stress than inrush. Flashover refers to the arc developed between the broken ends of the filament when the light bulb burns out. Ionization within the bulb allows the arc to flow directly between the internal lead-in wires, and current is then limited only by line impedance. Because of the large currents associated with flashover, incandescent light bulbs have fuses built into the stem to open circuit at the bulb without opening the line circuit breaker. On low-wattage bulbs, the arc continues until the bulb fuse opens, and may last for somewhat more than one half cycle. Damage or degradation of the triac can be avoided by selection of a triac that has surge capability in excess of the flashover currents which can occur. A device capable of handling a one-cycle peak current of 100 amperes or more is adequate for most installations using up to 150-watt bulbs. When the triac has inadequate surge capability for a particular application, special high-speed fuses or circuit breakers, external resistors, or other current limiting devices such as chokes may be used.

Light-Dimmer Circuits

Fig. 11 shows a single-time-constant circuit; Fig. 12 shows a double-time-constant circuit. Both are complete circuits suitable for operation at 120 or 240 volts ac, 50 or 60 Hz. The chart with each circuit specifies the values of components which change with the line voltage. The resistor in series with the potentiometer in each circuit is used to protect the potentiometer by limiting the current when the potentiometer is at the low-resistance end of its range.

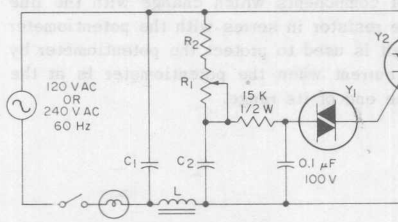
It is important to remember that a triac in these circuits dissipates power at the rate of about one watt per ampere. Therefore, some means of removing heat must be provided to keep the device within its safe operating-temperature range. On a small light-control circuit such as one built into a lamp socket, the lead-in wire serves as an effective heat sink. Attachment of the triac case directly to one of the lead-in wires provides sufficient heat dissipation for operating currents up to 2 amperes (rms). On wall-mounted controls operating up to 6 amperes, the combination of face plate and wallbox serves as an effective heat sink. For higher-power controls, however, the ordinary face plate and wallbox do not provide sufficient heat-sinking area. In this case, additional area may be obtained by use of a finned face plate that has a cover plate which stands out from the wall so air can circulate freely over the fins.

On wall-mounted controls, it is also important that the triac be electrically isolated from the face plate, but at the same time be in good thermal contact with it. Although the thermal conductivity of most electrical insulators is relatively low when compared with metals, a low-thermal-resistance, electrically isolated bond of triac to face plate can be obtained if the thickness of



	120 VAC, 60 Hz	240 VAC, 50/60 Hz
R_2	3300 ohms, ½W	4700 ohms, ½W
C_1	0.05 μF, 100V	0.1 μF, 100V
C_2	0.05 μF, 100V	0.10 μF, 100V (60 Hz) 0.12 μF, 100V (50 Hz)
L	100 μH	200 μH
Y_1	D3202U	D3202U
Y_2	T2800B	T2800D

Fig.11 - Single-time-constant light-dimmer circuit.



	120 VAC, 60 Hz	240 VAC, 50/60 Hz
R_1	0.1 megohm, ½W	3300 ohms, ½W
R_2	2200 ohms, ½W	0.2 megohm, 1W (60 Hz) 0.25 megohm, 1W (50 Hz)
C_1C_2	0.1 μF, 200V	0.1 μF, 400V
L	100 μH	200 μH
Y_1	D3202U	D3202U
Y_2	T2800B	T2800D

Fig.12 - Double-time-constant light-dimmer circuit.

the insulator is minimized, and the area for heat transfer through the insulator is maximized. Suitable insulating materials are fiber-glass tape, ceramic sheet, mica, and polyimide film. Fig. 13 shows two examples of isolated mounting for triacs: in Fig. 13(a), a TO-5 package; in Fig. 13(b), the new plastic package. Electrical insulating tape is first placed over the inside of the face plate. The triac is then mounted to the insulated face plate by use of epoxy-resin cement.

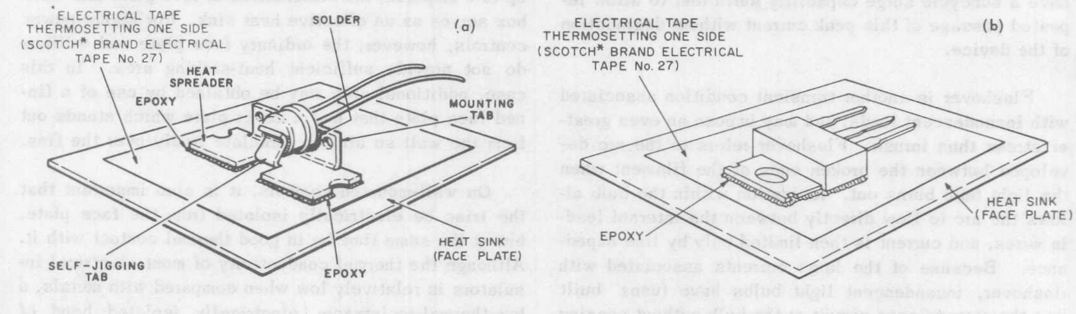


Fig.13 Examples of isolated mounting of triacs.

Trouble Shooting

Some malfunctions which can occur in light-dimming circuits are listed with their possible causes, as follows:

	Component	Possible Cause
Light remains on full intensity and will not dim.	Triac	Shorted in both directions caused by flashover or high current surge.
	Wiring	Anode-cathode or anode-gate shorted.
Light intensity can be varied but fails to reach zero.	Triac	Breakover voltage reduced in one or both directions.
	Diac	Low breakover voltage.
	Triggering Capacitor	Capacitance too low.
	Potentiometer	Maximum resistance too low.
Discontinuity in brightness at about half intensity.	Triac	I_{GT} too high in one mode.
	Diac	Breakover not symmetrical.
Flickering exists at low intensity.	Triac	Low commutating $dv/_{dt}$ capability. Flickering stops when the inductor is shorted.
Light out over most of the control range; turns on full intensity near low resistance end of potentiometer.	Triac	I_{GT} too high.
	Diac	Voltage breakback too low.
	Wiring	Diac not included or shorted out.
Same effect as preceding, but accompanied by arcing in potentiometer.	Triac	Internal short gate to cathode (very unlikely because such devices are rejected by 100 per cent electrical test).
	Capacitor	Shorted (this condition destroys the potentiometer, but not the triac).
	Wiring	Open anode contact (this condition destroys both the potentiometer and the triac). Cathode to gate short (this condition destroys only the potentiometer).
Light fails to turn on at all.	Triac	Open gate contact (very unlikely due to the 100 per cent electrical test by manufacturer).
	Diac	Open
	Potentiometer	Open
	Wiring	Open circuit at potentiometer, diac, triac gate, or cathode.

RCA

Solid State Division

Thyristors Application Note AN-3780

A New Horizontal-Deflection System Using RCA S3705M and S3706M Silicon Controlled Rectifiers

This Note describes a highly reliable horizontal-deflection system designed for use in the RCA CTC-40 solid-state color television receiver. This system illustrates a new approach in horizontal-circuit design that represents a complete departure from the approaches currently used in commercial television receivers. The switching action required to generate the scan current in the horizontal yoke windings and the high-voltage pulse used to derive the dc operating voltages for the picture tube is controlled by two silicon controlled rectifiers (SCR's) that are used in conjunction with associated fast-recovery diodes to form bipolar switches.

The RCA-S3705M SCR used to control the trace current and the RCA-S3706M SCR that provides the commutating action to initiate trace-retrace switching exhibit the high voltage- and current-handling capabilities, together with the the excellent switching characteristics, required for reliable operation in deflection-system applications. The switching diodes, RCA-D2601EF (trace) and D2601DF (commutating), provide fast recovery times, high reverse-voltage blocking capabilities, and low turn-on voltage drops. These features and the fact that, with the exception of one non-critical triggering pulse, all control voltages, timing, and control polarities are supplied by passive elements within the system (rather than by external drive sources) contribute substantially to the excellent reliability of the SCR deflection system.

SYSTEM PERFORMANCE

Fig. 1 shows the circuit configuration of the over-all horizontal-deflection system. The system operates directly from a conventional, unregulated dc power supply of +155 volts, provides full-screen deflection at angles up to 90 degrees at full beam current (1.5 milliamperes average in the CTC-40 receiver). The current and voltage waveforms required for horizontal deflection and for generation of the high voltage are derived essentially from LC resonant circuits. As a result, fast and abrupt switching transients, which would impose strains on the solid-state devices, are avoided.

A regulator stage is included in the SCR horizontal-deflection circuit to maintain the scan and the high voltage within acceptable limits with variations in the ac line voltage or picture-tube beam current. The system also contains circuits that provide full protection against the effects of arcs in the picture tube or the high-voltage rectifier and linearity and pincushion correction circuits. Each individual part of the deflection system is designed to specifications that are compatible with achievement of the following system performance:

Picture Tube

25-inch, 90-degree color type; neck diameter = 1 7/16 inches (i.e., similar to RCA-Type 25XP22)

Ultor Voltage, Beam Current, and Regulation

26.5 kilovolts at zero beam current or 24.5 kilovolts at 1.5 milliamperes (average) of beam current for ac line voltages of 120 to 130 volts rms

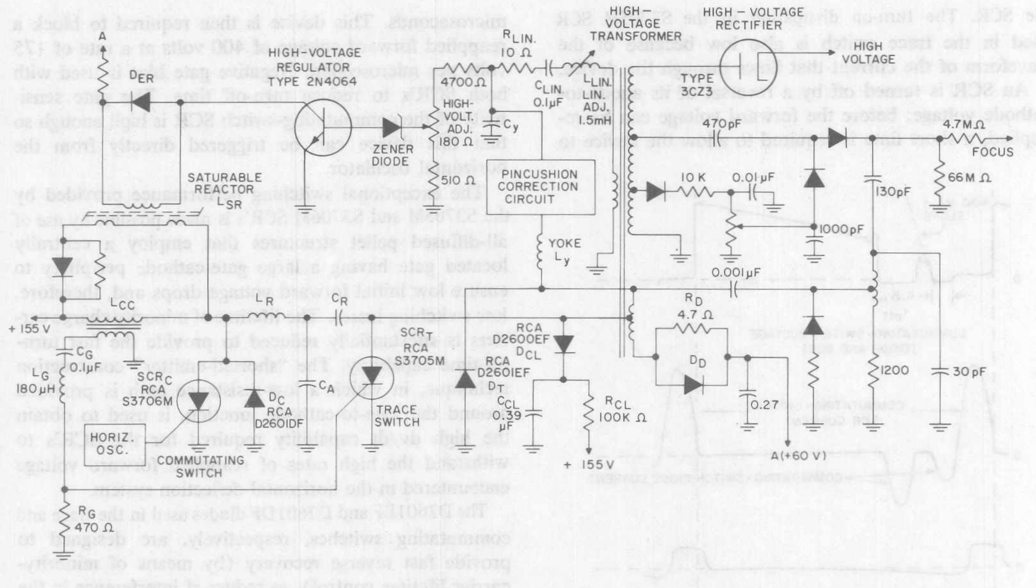


Fig. 1 — General circuit configuration of the over-all SCR horizontal-deflection system.

24.5 kilovolts at 1 milliampere of beam current for ac line voltages of 108 to 130 volts rms

22.5 kilovolts at 1.5 milliamperes of beam current for an ac line voltage of 105 volts rms

Input Current

420 milliamperes at zero beam current

670 milliamperes at 1.5 milliamperes of beam current

DC Input Voltage (Nominal)

155 volts at zero beam current

148 volts at 1.5 milliamperes of beam current

Scan Regulation*

¼-inch change for variation in ac line voltage from 105 to 130 volts rms

¼-inch change for beam-current variation of 0.3 to 1.5 milliamperes at a line voltage of 120 volts rms

Linearity*

Deviation in picture width is equal to or less than 5 per cent, left to right

Retrace Time

Flyback pulse width = 12.5 microseconds at zero crossing of yoke voltage

Total flyback pulse width = 14 microseconds at extremes of yoke voltage

Trigger Input

10-volt, 5-microsecond pulse (obtained directly from horizontal oscillator)

Pincushion Correction

Top and bottom pincushion correction provided for a minimum radius of 150 inches

REQUIREMENTS OF THE SWITCHING SCR's AND DIODES

The SCR horizontal-deflection circuit requires fast reverse recovery for both the switching SCR's and the diodes and fast turn-on for the SCR's. The S3705M and S3706M SCR's and the D2601EF and D2601DF diodes are well suited to provide this type of performance. (Detailed specifications for the SCR's and diodes are given in the published data on the devices). The exceptional capabilities of these devices are illustrated by the performance that they provide in the horizontal-deflection system. Fig. 2 shows the significant current and voltage waveforms that the SCR's and diodes are subjected to during operation of the deflection circuit.

The S3706M SCR used in the commutating switch is required to pass a pulse of current that has a peak amplitude of 13 amperes and an initial rate of rise of 20 amperes per microsecond. At the operating frequency of the horizontal-deflection circuit, achievement of this performance requires low turn-on dissipation in

* The deflection system is not subject to degradation of scan or linearity during component life.

...of the current that flows through the device.

An SCR is turned off by a reversal of its anode-to-cathode voltage; before the forward voltage can be reapplied, a short time is required to allow the device to

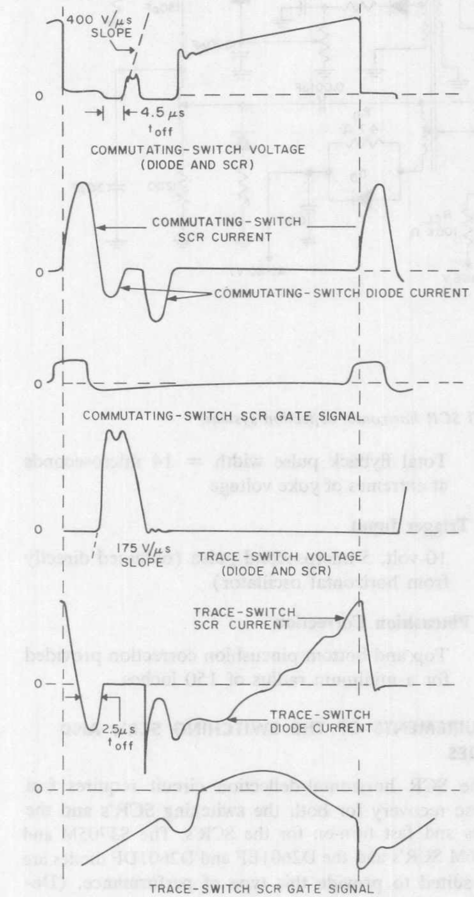


Fig. 2 — Voltage and current waveforms applied to the SCR's and diodes used to control the switching actions in the SCR horizontal-deflection system.

regain its forward-blocking capability. Under worst-case conditions, the available turn-off time for the commutating switch requires the use of an SCR that can be completely turned off in 4.5 microseconds. The SCR must then be able to block a reapplied forward voltage of 100 volts applied at a rate of 400 volts per microsecond. The turn-off requirement for the trace-switch SCR, under worst-case circuit conditions, is 2.5 volts per microsecond. Negative gate bias is used with both SCR's to reduce turn-off time. The gate sensitivity of the commutating-switch SCR is high enough so that this device can be triggered directly from the horizontal oscillator.

The exceptional switching performance provided by the S3705M and S3706M SCR's is made possible by use of all-diffused pellet structures that employ a centrally located gate having a large gate-cathode periphery to ensure low initial forward voltage drops and, therefore, low switching losses. The lifetime of minority charge carriers is substantially reduced to provide the fast turn-off-time capability. The "shorted-emitter" construction technique, in which a low-resistance path is provided around the gate-to-cathode junction, is used to obtain the high dv/dt capability required for the SCR's to withstand the high rates of reapplied forward voltage encountered in the horizontal-deflection system.

The D2601EF and D2601DF diodes used in the trace and commutating switches, respectively, are designed to provide fast reverse recovery (by means of minority-carrier lifetime control), to reduce rf interference in the circuit, and to decrease diode recovery losses. The slope and magnitude of the reverse-recovery current in the diodes have been optimized to ensure minimum reverse-recovery dissipation and to prevent rf interference because of overly abrupt recovery. The fast recovery characteristics have been achieved while maintaining a low turn-on voltage drop and a high reverse-voltage blocking capability.

OPERATION OF THE BASIC DEFLECTION CIRCUIT

The essential components in the SCR horizontal-deflection system required to develop the scan current in the yoke windings are shown in Fig. 3. Essentially

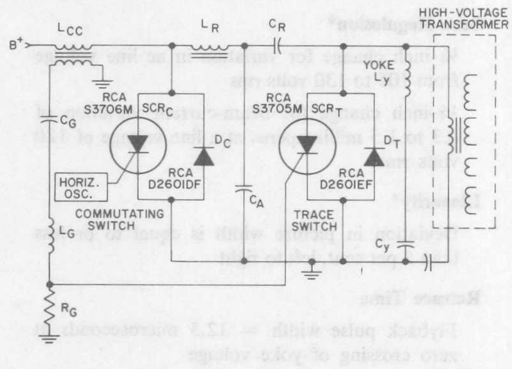


Fig. 3 — Basic circuit for generation of the deflection-current waveform in the horizontal yoke winding.

the trace-switch diode D_T and the trace-switch controlled rectifier SCR_T provide the switching action which controls the current in the horizontal yoke windings L_y during the picture-tube beam-trace interval. The commutating-switch diode D_C and the commutating-switch controlled rectifier SCR_C initiate retrace and control the yoke current during the retrace interval. Inductor L_R and capacitors, C_R, C_A, and C_y provide the necessary energy storage and timing cycles. Inductor L_{CC} supplies a charge path for capacitor C_R from the dc supply voltage (B+) so that the system can be recharged from the receiver power supply. The secondary of inductor L_{CC}, provides the gate trigger voltage for the trace-switch SCR. Capacitor C_R establishes the optimum retrace time by virtue of its resonant action with inductor L_R.

The complete horizontal-deflection cycle may best be described as a sequence of discrete intervals, each terminated by a change in the conduction state of a switching device. In the following discussion, the action of the auxiliary capacitor C_A and the flyback high-voltage transformer are initially neglected to simplify the explanation.

First Half of the Trace Interval

Fig. 4 shows the circuit elements involved and the voltage and current relationships during the first half of the trace deflection-current interval, the period from T_0 to T_2. At time T_0, the magnetic field has been established about the horizontal yoke windings L_y by the circuit action during the retrace period of the preceding cycle (explained in the subsequent discussion of retrace intervals). This magnetic field generates a decaying yoke current i_y that decreases to zero when the energy in the yoke winding is depleted (at time T_2). This current charges capacitor C_y to a positive voltage V_{C_y} through the trace-switch diode D_T.

During the first half of the trace interval (just prior to time T_2) the trace controlled rectifier SCR_T is made ready to conduct by application of an appropriate gate voltage pulse V_{GATE}. SCR_T does not conduct, however, until a forward bias is also applied between its anode and cathode. This voltage is applied during the second half of the trace interval.

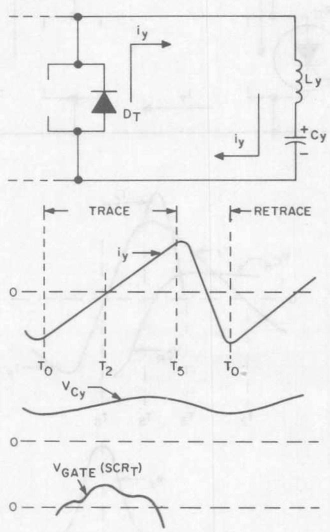


Fig. 4 — Effective configuration of the deflection circuit during the first half of the trace interval, time T_0 to T_2, and operating voltage and current waveforms for the complete trace-retrace cycle.

Second Half of the Trace Interval

At time T_2, current is no longer maintained by the yoke inductance, and capacitor C_y begins to discharge into this inductance. The direction of the current in the circuit is then reversed, and the trace-switch diode D_T becomes reverse-biased. The trace-switch controlled rectifier SCR_T, however, is then forward-biased by the voltage V_{C_y} across the capacitor, and the capacitor discharges into the yoke inductance through SCR_T, as indicated in Fig. 5. The capacitor C_y

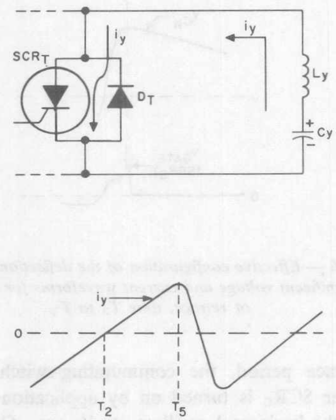


Fig. 5 — Effective configuration of the deflection circuit during the second half of the trace interval, time T_2 to T_5, and the complete scan-current waveform.

is sufficiently large so that the voltage V_{C_y} remains essentially constant during the entire trace and retrace

cycle. This constant voltage results in a linear rise in current through the yoke inductance L_y over the entire scan interval from T_0 to T_5.

Start of the Retrace Interval

The circuit action to initiate retrace starts before the trace interval is completed. Fig. 6 shows the circuit elements and the voltage and current waveforms required for this action. At time T_3, prior to the end of

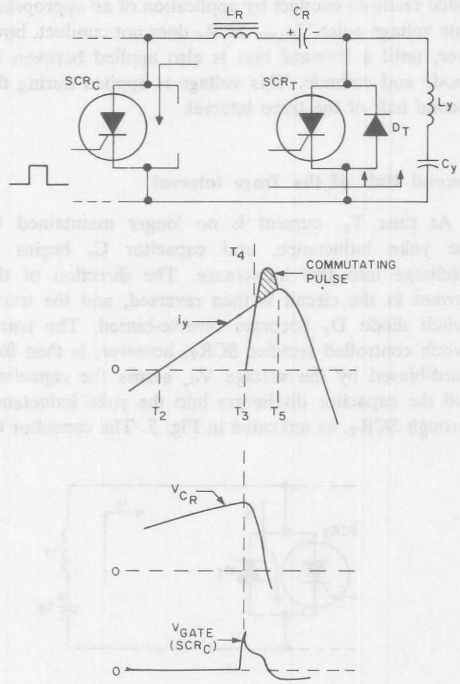


Fig. 6 — Effective configuration of the deflection circuit and significant voltage and current waveforms for initiation of retrace, time T_3 to T_5.

the trace period, the commutating-switch controlled rectifier SCR_C is turned on by application of a pulse from the horizontal oscillator to its gate. Capacitor C_R is then allowed to discharge through SCR_C and inductor L_R. The current in this loop, referred to as the commutating circuit, builds up in the form of a half-sine-wave pulse. At time T_4, when the magnitude of this current pulse exceeds the yoke current, the trace-switch diode D_T again becomes forward-biased. The excess current in the commutating pulse is then bypassed around the yoke winding by the shunting action of diode D_T. During the time from T_4 to T_5, the trace-switch controlled rectifier SCR_T is reverse-biased by the amount of the voltage drop across diode D_T. The trace-switch controlled rectifier, therefore, is turned off during this interval and is allowed to recover its ability to block the forward voltage that is subsequently applied.

First Half of the Retrace Interval

At time T_5, the commutating pulse is no longer greater than the yoke current, as shown in Fig. 7; trace-switch diode D_T then ceases to conduct. The yoke inductance maintains the yoke current but, with SCR_T in the OFF state, this current now flows in the commutating loop formed by L_R, C_R, and SCR_C. Time T_5 is the beginning of retrace.

As the current in the yoke windings decreases to zero, the energy supplied by this current charges capacitor C_R with an opposite-polarity voltage in a resonant oscillation. At time T_6, the yoke current is zero, and capacitor C_R is charged to its maximum negative voltage value. This action completes the first half of retrace.

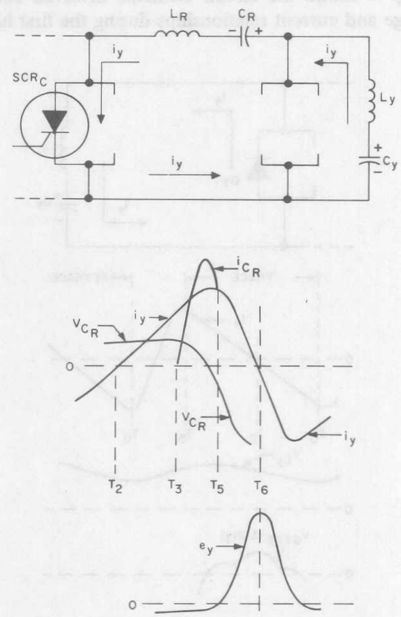


Fig. 7 — Effective configuration of the deflection circuit and operating voltage and current waveforms during the first half of retrace, time T_5 to T_6.

Second Half of the Retrace Interval

At time T_6, the energy in the yoke inductance is depleted, and the stored energy on the retrace capacitor C_R is then returned to the yoke inductance. This action reverses the direction of current flow in the yoke. During the reversal of yoke current, the commutating-switch diode D_C provides the return path for the loop current, as indicated in Fig. 8. The commutating-switch controlled rectifier SCR_C is reverse-biased by the amount of the voltage drop across diode D_C. The commutating-switch controlled rectifier, therefore, turns off and recovers its voltage-blocking capability. As the yoke current builds up in the negative direction, the voltage on the retrace capacitor C_R is decreased. At time T_0, the voltage across capacitor C_R no longer provides a driving voltage for the yoke current to flow in the loop formed by L_R, C_R, and L_y. The yoke current finds an easier path up through trace-switch diode D_T, as shown in Fig. 9. This action represents the beginning of the trace period for the yoke current (i.e., the start of a new cycle of operation), time T_0.

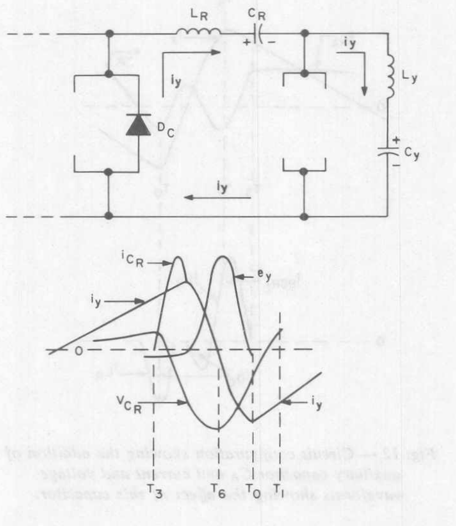


Fig. 8 — Effective configuration of the deflection circuit and operating voltage and current waveforms during the second half of retrace, time T_6 to T_0.

Once the negative yoke current is decoupled from the commutating loop by the trace-switch diode, the current in the commutating circuit decays to zero. The stored energy in the inductor L_R charges capacitor C_R to an initial value of positive voltage. Because the resonant frequency of L_R and C_R is high, this transfer is accomplished in a relatively short period, T_0 to T_1, as shown in Fig. 8.

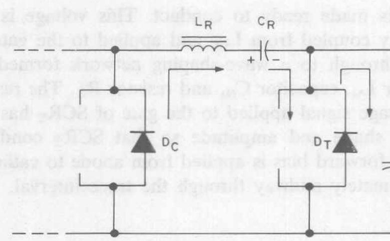


Fig. 9 — Effective configuration of the deflection circuit during the switchover from retrace to trace, time T_0.

Recharging and Resetting Actions

The actions required to restore energy to the commutating circuit and to reset the trace SCR are also very important considerations in the operation of the basic deflection circuit. Both actions involve the inductor L_{CC}.

During the retrace period, inductor L_{CC} is connected between the dc supply voltage (B+) and ground by the conduction of either the commutating-switch SCR or diode (SCR_C or D_C), as indicated in Fig. 10. When the diode and the SCR cease to conduct, however, the path from L_{CC} to ground is opened. The energy stored in inductor L_{CC} during the retrace interval then charges capacitor C_R through the B+ supply, as shown in Fig. 11. This charging process continues through the trace period until retrace is again initiated. The resultant charge on capacitor C_R is used to resupply energy to the yoke circuit during the retrace interval.

The voltage developed across inductor L_{CC} during the charging of capacitor C_R is used to forward-bias the gate electrode of the trace SCR properly so that this

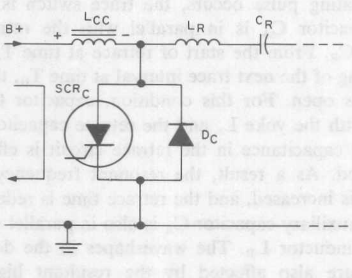


Fig. 10 — Circuit elements and current path used to supply energy to the charging choke Lcc during period from the start of retrace switching action to the end of the first half of the retrace interval, time T_3 to T_1.

device is made ready to conduct. This voltage is inductively coupled from L_{CC} and applied to the gate of SCR_T through to a wave-shaping network formed by inductor L_G, capacitor C_G, and resistor R_G. The resulting voltage signal applied to the gate of SCR_T has the desired shape and amplitude so that SCR_T conducts when a forward bias is applied from anode to cathode, approximately midway through the trace interval.

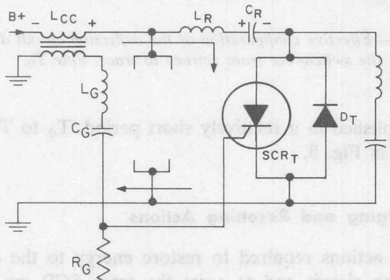


Fig. 11 — Effective configuration of the deflection circuit for resetting (application of forward bias to) the trace SCR and recharging the retrace capacitor C_R, during time interval from T_1 to T_3.

Effect of Auxiliary Capacitor C_A

In the preceding discussions of the operation of the deflection circuit, the effect of capacitor C_A was neglected. Inclusion of this capacitor affects some of the circuit waveforms, as shown in Fig. 12, aids in the turn-off of the trace SCR, reduces the retrace time, and provides additional energy-storage capability for the circuit.

During most of the trace interval (from T_0 to T_4), including the interval (T_3 to T_4) during which the commutating pulse occurs, the trace switch is closed, and capacitor C_A is in parallel with the retrace capacitor C_R. From the start of retrace at time T_4 to the beginning of the next trace interval at time T_0, the trace switch is open. For this condition, capacitor C_A is in series with the yoke L_y and the retrace capacitor C_R so that the capacitance in the retrace circuit is effectively decreased. As a result, the resonant frequency of the retrace is increased, and the retrace time is reduced.

The auxiliary capacitor C_A is also in parallel with the retrace inductor L_R. The waveshapes in the deflection circuit are also affected by the resultant higher-frequency resonant discharge around this loop. The voltage and current waveforms shown in Fig. 12 illustrate the effects of the capacitor C_A.

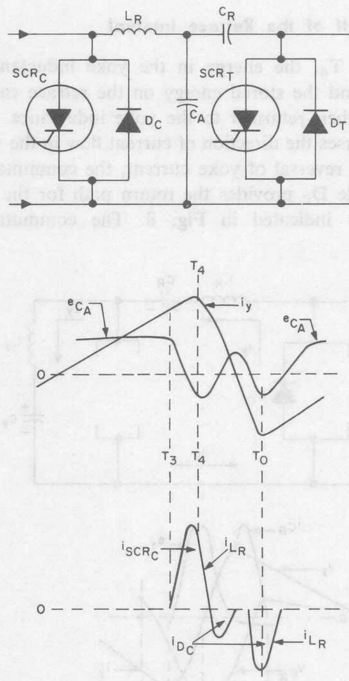


Fig. 12 — Circuit configuration showing the addition of auxiliary capacitor C_A and current and voltage waveforms showing the effect of this capacitor.

HIGH-VOLTAGE GENERATION

The SCR horizontal-deflection system in the RCA CTC-40 receiver generates the high voltage for the picture tube in essentially the same manner as has been used for many years in other commercial television receivers, i.e., by transformation of the horizontal-deflection retrace (flyback) pulse to a high voltage with a voltage step-up transformer and subsequent rectification of this stepped-up voltage. The RCA-3CZ3 electron tube is used as the high-voltage rectifier in the RCA CTC-40 television receiver.

Fig. 13 shows schematic of the over-all high-voltage circuit, and Fig. 14 shows a simplified schematic of this circuit together with the significant voltage and current waveforms. The high-voltage transformer is connected across the yoke and retrace capacitor. The inductance and capacitance of this transformer are such that it presents a load tuned to about the third harmonic of the retrace resonant frequency. The presence of this load adds harmonic components to the waveforms previously described.

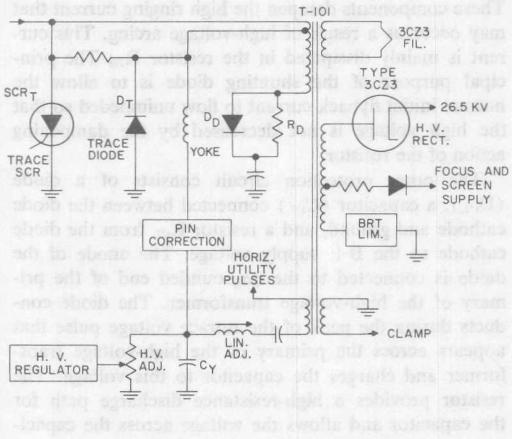


Fig. 13 — High-voltage circuit.

HIGH-VOLTAGE REGULATION

The high voltage is regulated by controlling the amount of energy made available to the horizontal-output trace circuit. As stated previously, the trace circuit is supplied by energy which is stored primarily on the commutating capacitor C_R. This capacitor is charged during the trace interval through inductance L_{CC}.

Control of the high-voltage energy on the commutating capacitor is made possible by the design of inductor L_{CC} so that it approaches resonance with capacitor C_R; the degree of this resonance can be varied by the high-voltage regulator circuit.

Fig. 15 illustrates the effect of this resonant action on the charge on the commutating capacitor. The waveshape that results from the resonant action determines the amount of charge that will be on the capacitor when its energy is released into the trace circuit.

The resonance of the inductor L_{CC} and the commutating capacitor C_R is varied by use of a saturable reactor L_{SR} to control the inductance across L_{CC}. The saturable-reactor load winding is placed in parallel with L_{CC}. Changes in the current through the reactor control windings varies the total inductance of the input circuit. The current in the reactor load winding is controlled by the pulse regulator circuit.

The control current for the reactor control winding is determined by the conduction of the high-voltage regulator transistor Q_X. The collector current of this transistor is in turn controlled by the voltage across the yoke-return capacitor C_y. This voltage, which is directly proportional to high voltage and which tracks any changes in the high voltage, is sampled by the high-voltage adjustment control and compared to a reference voltage determined by a Zener diode. The resulting difference voltage, which is indicative of changes in the high voltage, controls the conduction of the regulator transistor.

As the high-voltage load (beam current) decreases, the high voltage tends to increase. The voltage across the yoke-return capacitor then tends to increase. This action results in an instantaneously higher current pulse through the base-emitter junction of the regulator transistor. The reactor control current, therefore, tends to increase proportionally, so that the total inductance of the input circuit is decreased. The resulting change in resonance of L_{CC}, L_{SR}, and C_R reduces the charge on C_R and the energy made available to the trace circuit. In this way, the high voltage is stabilized. The reverse action, of course, occurs if the high voltage tends to decrease.

Diode D_{ER} acts as an energy-recovery diode which improves the efficiency of the control circuit. The regulator transistor actually conducts only for a very short time, and the majority of the control current is supplied by diode conduction. This high-voltage regulating system also maintains the high voltage within acceptable limits for variations in the ac line voltage over the range from 105 to 130 volts.

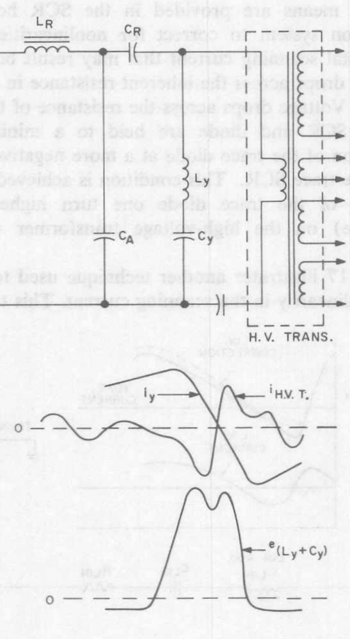


Fig. 14 — Simplified schematic and significant voltage and current waveforms for the high-voltage circuit.

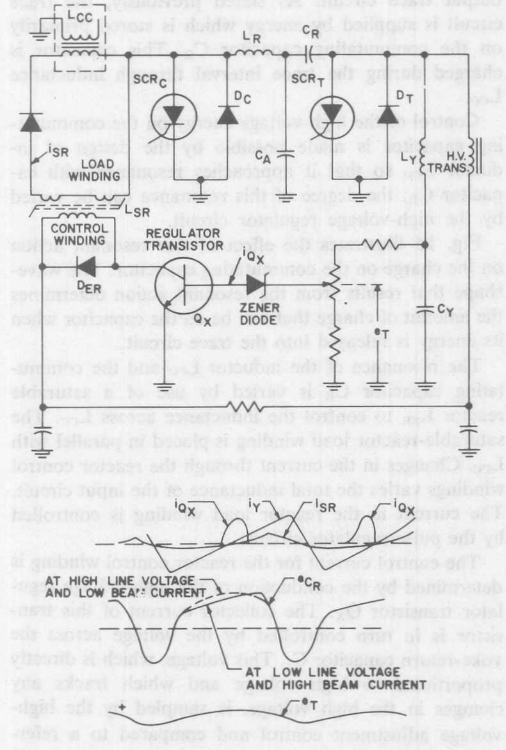


Fig. 15 — High-voltage regulator and operating voltage and current waveforms.

ARC PROTECTION

Two circuits are included in the SCR deflection system to protect the trace-switch SCR and diode from high voltages and currents that may result because of arcing from the high-voltage rectifier or the picture tube. These circuits are shown in Fig. 16.

One circuit includes the parallel combination of a diode (D_D) and a 4.7-ohm resistor (R_D) connected in series with the primary of the high-voltage transformer.

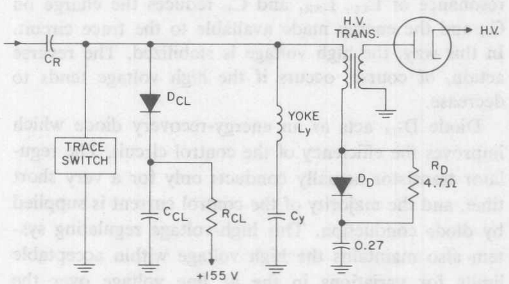


Fig. 16 — Arc-protection circuits.

These components dampen the high ringing current that may occur as a result of high-voltage arcing. This current is mainly dissipated in the resistor R_D; The principal purpose of the shunting diode is to allow the normal initial flyback current to flow unimpeded so that the high voltage is not decreased by the dampening action of the resistor.

The other protection circuit consists of a diode (D_{CL}), a capacitor (C_{CL}) connected between the diode cathode and ground, and a resistor R_{CL} from the diode cathode to the B+ supply voltage. The anode of the diode is connected to the ungrounded end of the primary of the high-voltage transformer. The diode conducts during the peak of the retrace voltage pulse that appears across the primary of the high-voltage transformer and charges the capacitor to this voltage. The resistor provides a high-resistance discharge path for the capacitor and allows the voltage across the capacitor to be reduced just enough to keep the diode reverse-biased during the retrace interval. When a sharp voltage pulse is produced because of high-voltage arcing, the diode conducts so that the trace switch is clamped to the voltage across the capacitor. The arc pulse voltage, therefore, is not allowed to exceed the breakdown voltage of the trace-switch components.

LINEARITY CORRECTION

Two means are provided in the SCR horizontal-deflection system to correct for nonlinearities in the horizontal scanning current that may result because of voltage drops across the inherent resistance in the trace circuit. Voltage drops across the resistance of the trace-switch SCR and diode are held to a minimum by operation of the trace diode at a more negative voltage than the trace SCR. This condition is achieved by connection of the trace diode one turn higher (more negative) on the high-voltage transformer than the SCR.

Fig. 17 illustrates another technique used to correct for nonlinearity in the scanning current. This technique

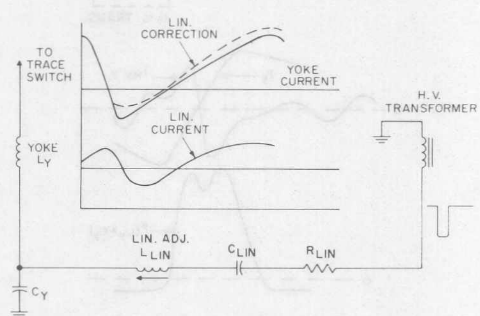


Fig. 17 — Linearity-correction circuit and correction-current waveforms.

uses a damped series resonant circuit (L_{LIN}, C_{LIN}, and R_{LIN}), connected between a winding on the high-voltage transformer and the ungrounded side of the yoke-return capacitor C_y, to produce a damped sine wave of current that effectively adds to and subtracts from the charge on the yoke-return capacitor C_y. The resulting alteration in yoke current corrects for any trace-current nonlinearities.

ADVANTAGES OF THE SCR HORIZONTAL-DEFLECTION SYSTEM

It is apparent from the preceding discussions that the SCR horizontal-deflection system offers a number of distinct advantages over the conventional types of systems currently used in commercial television receivers. The following list outlines some of the more significant circuit features of the SCR deflection system and points out the advantage derived from each of them:

1. Critical voltage and current waveforms, and timing cycles are determined by passive components in response to the action of two SCR-diode switches. The stability of the system, therefore, is determined primarily by the passive components. When the passive components are properly adjusted, the system exhibits highly predictable performance characteristics and exceptional operational dependability.

2. The only input drive signal required for the SCR deflection system is a low-power pulse which has no stringent accuracy specification in relation to either amplitude or time duration. The deflection system, therefore, can be driven directly from a pulse developed by the horizontal oscillator.

3. This deflection system is unique in that, although it operates from a conventional B+ supply of +155 volts, the flyback pulse is less than 500 volts. This level of voltage stress is substantially less than that in conventional line-operated systems, and this factor contributes to improved reliability of the switching devices.

4. Regulation in the SCR deflection system is accomplished by control of the energy stored by a reactive element. This technique avoids the use of resistive-load regulating elements required by many other types of systems and, therefore, makes possible higher over-all system efficiency and reduces input-power requirements.

5. All switching occurs at the zero current level through the reverse recovery of high-voltage p-n junctions in the deflection diodes. The diode junctions are not limited in volt-ampere switching capabilities for either normal or abnormal conditions in the circuit.

RCA
Solid State
Division

Thyristors
Application Note
AN-3822

Thermal Considerations in Mounting of RCA Thyristors

by

J. M. S. Neilson

Consideration of thermal problems involved in the mounting of thyristors is synonymous with consideration of the best heat sink for a particular application. Most practical heat sinks used in modern, compact equipment are the result of experiments with heat transfer through convection, radiation, and conduction in a given application. Although there are no set design formulas that provide exact heat-sink specifications for a given application, there are a number of simple rules that reduce the time required to evolve the best design for the job. These simple rules are as follows:

1. The surface area of the heat sink should be as large as possible to provide the greatest possible heat transfer. The area of the surface is dictated by thyristor case-temperature requirements and the environment in which the thyristor is to be placed.
2. The heat-sink surface should have an emissivity value near unity for optimum heat transfer by radiation. A value approaching unity can be obtained if the heat-sink surface is painted flat black.
3. The thermal conductivity of the heat-sink material should be such that excessive thermal gradients are not established across the heat sink.

Although these rules are followed in conventional heat-sink systems, the size and cost of such systems often become restrictive in compact, mass-produced power-control and power-switching applications using thyristors. These restrictions are overcome in RCA thyristors because the JEDEC TO-5 and "modified TO-5" packages shown in Figs.1 and 2 are tin-plated and can be soldered directly to a heat sink. The use of mass-

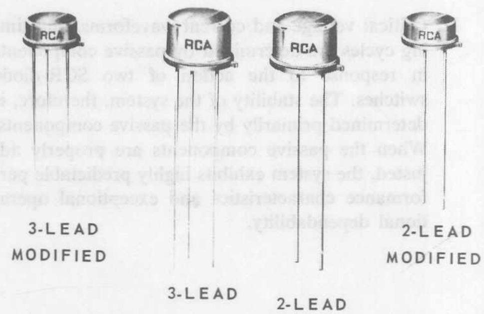


Fig.1 - RCA TO-5 thyristor packages.

produced prepunched parts, direct soldering, and batch-soldering techniques eliminates many of the difficulties associated with heat sinks by making possible the use of a variety of simple, efficient, readily fabricated heat-sink configurations that can be easily incorporated into the mechanical design of equipment.

Power Dissipation and Heat-Sink Area

The curves shown in Fig.3 are designed for use with the power-dissipation curves shown in the technical bulletins describing the various RCA thyristors. The curves of Fig.3 are conservative and can be used directly for thyristors having thermal-resistance ratings (θ_T), junction-to-case, of $5^{\circ}C/W$ or less. The curves shown in Fig.4 represent the power-dissipation characteristics of a typical thyristor. As an example of the use of Figs.3 and 4, it is assumed that an appropriate heat sink must be

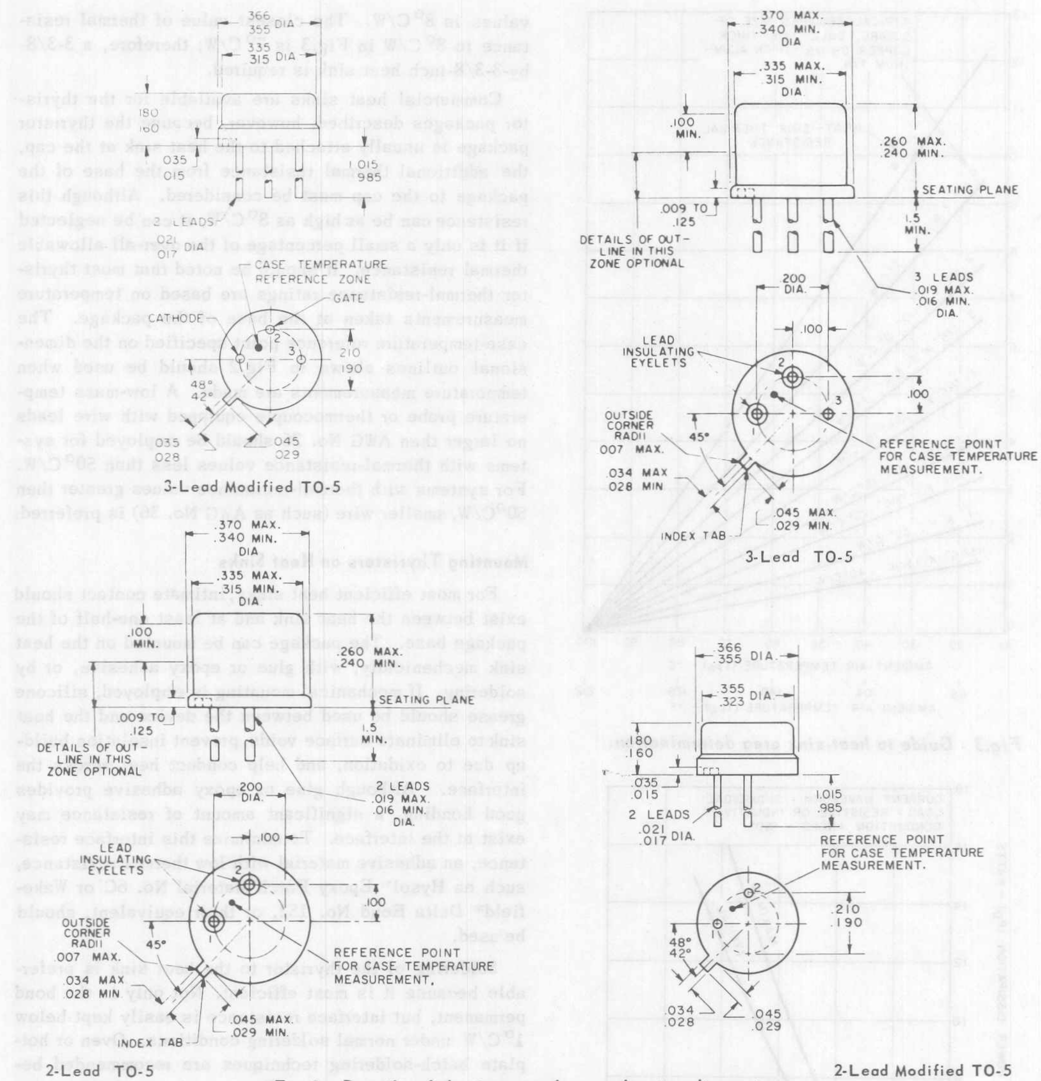


Fig.2 - Details of thyristor packages showing dimensions and reference point for case-temperature measurement.

found for a thyristor that is to conduct a current of 2 amperes, operate at an air temperature of 37°C, and be soldered to the heat sink at the base of the package. From Fig.4, the maximum power dissipation in the thyristor is found to be 3 watts. Fig.3 shows that the maximum allowable thermal resistance of the heat sink at this level of power dissipation is 15° C/W, and that a square, dull, 1/16-inch-thick copper or 1/8-inch-thick aluminum heat sink with an area of at least 1-3/4 by 1-1/4 inches is required.

The curves of Fig.3 can also be used with thyristors having junction-to-case thermal-resistance ratings of more than 5° C/W. However, the difference between the higher thermal-resistance value of the thyristor and the value of 5° C/W upon which the curves are based must be subtracted from the thermal-resistance values shown in Fig.3. For example, if it is assumed that the conditions are the same as those stated previously except that the thermal resistance, junction-to-case, of the device is 13° C/W, the difference in thermal-resistance

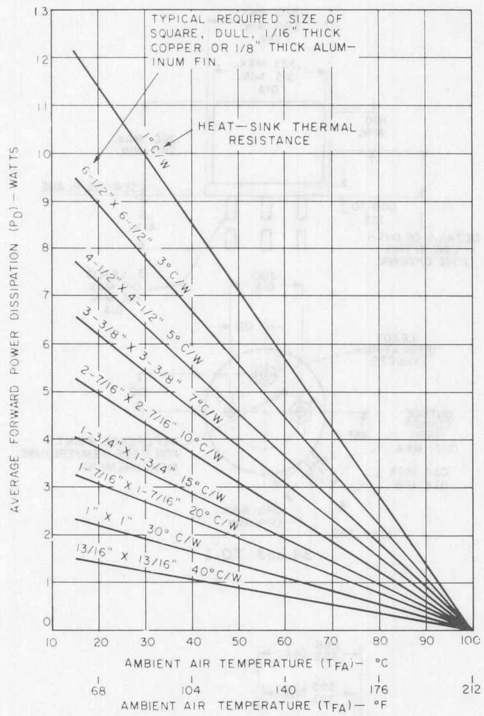


Fig.3 - Guide to heat-sink area determination.

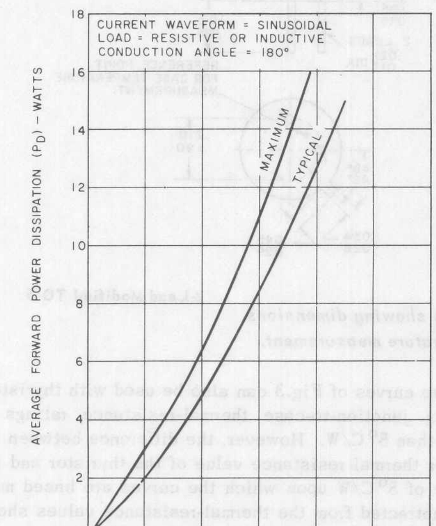


Fig.4 - Typical power-dissipation curves.

values is 8°C/W. The closest value of thermal resistance to 8°C/W in Fig.3 is 7°C/W; therefore, a 3-3/8-by-3-3/8-inch heat sink is required.

Commercial heat sinks are available for the thyristor packages described; however, because the thyristor package is usually attached to the heat sink at the cap, the additional thermal resistance from the base of the package to the cap must be considered. Although this resistance can be as high as 8°C/W, it can be neglected if it is only a small percentage of the over-all allowable thermal resistance. It should be noted that most thyristor thermal-resistance ratings are based on temperature measurements taken at the base of the package. The case-temperature reference point specified on the dimensional outlines shown in Fig.2 should be used when temperature measurements are made. A low-mass temperature probe or thermocouple equipped with wire leads no larger than AWG No. 26 should be employed for systems with thermal-resistance values less than 50°C/W. For systems with thermal-resistance values greater than 50°C/W, smaller wire (such as AWG No. 36) is preferred.

Mounting Thyristors on Heat Sinks

For most efficient heat sinks, intimate contact should exist between the heat sink and at least one-half of the package base. The package can be mounted on the heat sink mechanically, with glue or epoxy adhesive, or by soldering. If mechanical mounting is employed, silicone grease should be used between the device and the heat sink to eliminate surface voids, prevent insulation build-up due to oxidation, and help conduct heat across the interface. Although glue or epoxy adhesive provides good bonding, a significant amount of resistance may exist at the interface. To minimize this interface resistance, an adhesive material with low thermal resistance, such as Hysol* Epoxy Patch Material No. 6C or Wakefield* Delta Bond No. 152, or their equivalent, should be used.

Soldering of the thyristor to the heat sink is preferable because it is most efficient. Not only is the bond permanent, but interface resistance is easily kept below 1°C/W under normal soldering conditions. Oven or hot-plate batch-soldering techniques are recommended because of their low cost. The use of a self-jigging arrangement of the thyristor and the heat sink and a 60-40 solder preform is recommended. If each unit is soldered individually with a flame or electric soldering iron, the heat source should be held on the heat sink and the solder on the unit. Heat should be applied only long enough to permit solder to flow freely. Because RCA thyristors are tin-plated, maximum solder wetting is easily obtainable without thyristor overheating.

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* Products of Hysol Corporation, Olean, New York and Wakefield Engineering, Inc., Wakefield, Massachusetts, respectively.

The special high-conductivity leads on the two-lead TO-5 package permit operation of the thyristor at current levels that would be considered excessive for an ordinary TO-5 package. The special leads can be bent into almost any configuration to fit any mounting requirement; however, they are not intended to take repeated bending and unbending. In particular, repeated bending at the glass should be avoided. The leads are not especially brittle at this point, but the glass has a sharp edge which produces an excessively small radius of curvature in a bend made at the glass. Repeated bending with a small radius of curvature at a fixed point will cause fatigue and breakage in almost any material. For this reason, right-angle bends should be made at least 0.020 inch from the glass. This practice will avoid sharp bends and maintain sufficient electrical isolation between lead connections and header. A safe bend can be assured if the lead is gripped with pliers close to the glass seal and then bent the requisite amount with the fingers, as shown in Fig.5. When the leads of a number of devices are to be bent into a particular configuration, it may be advantageous to use a lead-bending fixture to assure that all leads are bent to the same shape and in the correct place the first time, so that there is no need for repeated bending.

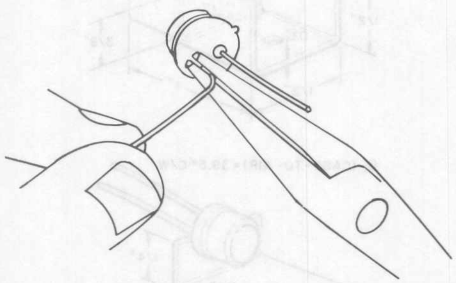

Fig.5 - Method of bending leads on thyristor package.

Typical Heat-Sink Configurations

Typical heat-sink designs that can be used with RCA thyristors are shown in Fig.6. The case-to-air thermal-resistance value for each of the easily fabricated sinks is given, along with approximate dimensions. The thyristors in the illustrations are soldered to the heat sink; if epoxy is used, an additional thermal resistance of $1^{o}C/W$ to $2^{o}C/W$ must be added to the thermal-resistance values shown. The junction-to-case thermal-resistance value for the particular thyristor being used should be added to the values shown to obtain the over-all junction-to-air thermal resistance of each configuration. In the designs shown, electrical insulation of the heat sink from the chassis or equipment housing may be required.

Chassis-Mounted Heat Sinks

In many applications, it is desirable and practical to use the chassis or equipment housing as the heat sink. In such cases, the thyristor must be electrically insulated from the heat sink, but must still permit heat generated by the device to be efficiently transferred to the chassis or housing. This heat transfer can be achieved by use of the heat-spreader mounting method. In this method, the thyristor is attached to a metal bracket (heat spreader) which is attached to, but electrically insulated from, the chassis. Examples of heat spreaders are shown in Figs.6 and 7. Electrical insulation may consist of material such as alumina ceramic, polyimide film or tape, fiberglass tape, or epoxy. The metal bracket itself has a low thermal resistance, and spreads the heat out over a larger area than could the thyristor case alone. The larger area in contact with the electrical insulation allows heat to transfer from bracket to chassis through the insulation with relatively low thermal resistance. Typical heat sinks, such as those shown in Fig.6, provide a much lower thermal resistance when used as heat spreaders than when used as heat sinks. Heat spreader dimensions can be varied over a wide range to suit particular applications. For example, area or diameter can be increased, or shape changed, as long as the heat-transfer area in contact with the electrical insulation is sufficient. An area of 0.2 square inch or more is usually desirable. The exact thermal resistance of any heat spreader depends on the heat-transfer area, type of metal used, type of insulation used, and whether the thyristor is fastened to the heat spreader with solder or epoxy. Soldered construction yields a thermal resistance about $1^{o}C/W$ less than that obtained with epoxy. Alumina or polyimide insulation provides a thermal resistance about 1 to $2^{o}C/W$ less than that obtained with thermosetting fiberglass-tape insulation. The heat spreader can be made of any material with suitable thermal conductivity, such as copper, brass, or aluminum. Solderable plating for aluminum is commercially available.

A self-jigging type of copper heat spreader is shown in Fig.7. SCR's soldered to this heat spreader are available from RCA as type numbers S2620B, S2620D, and S2620M.

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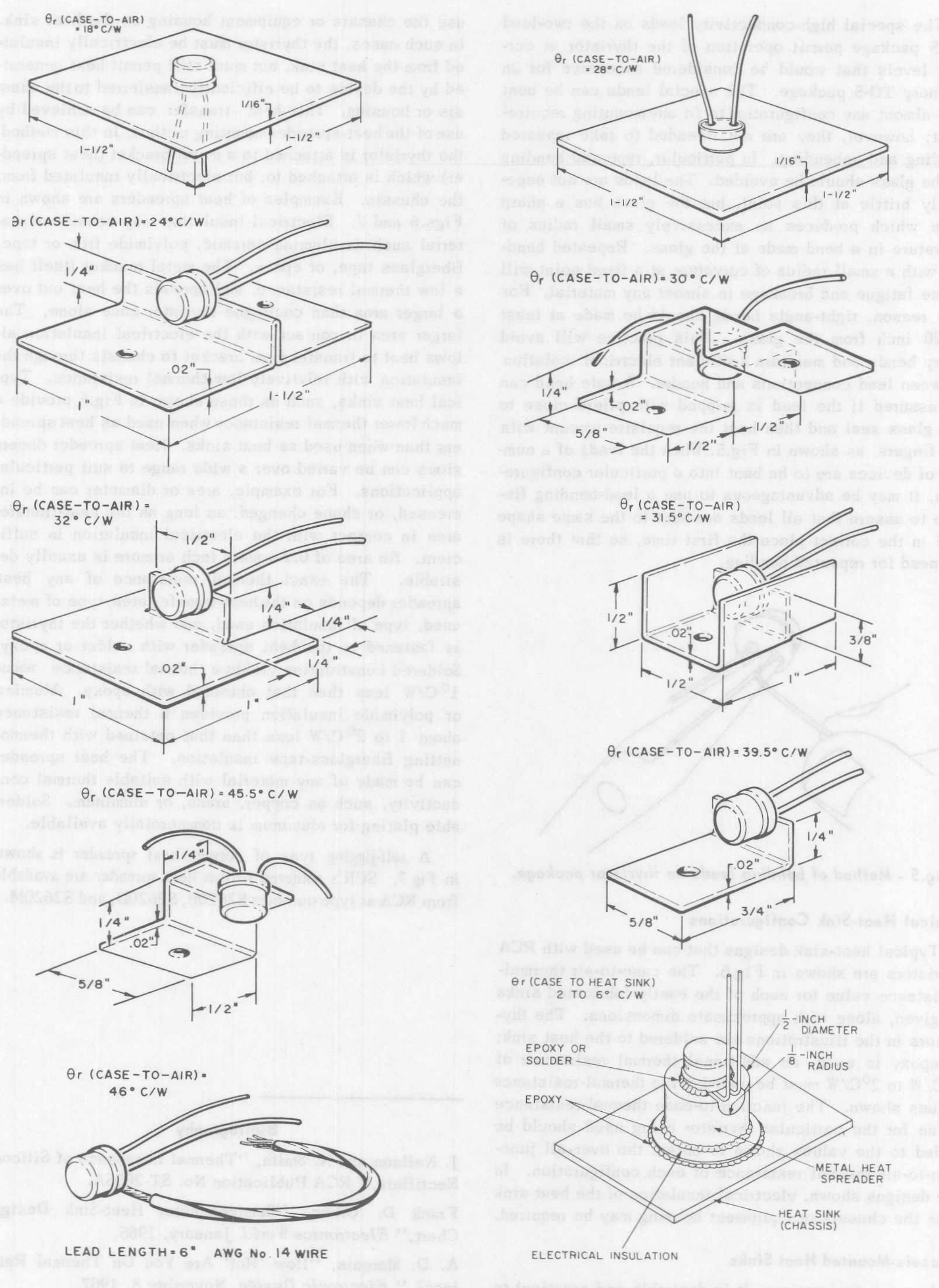


Fig.6 - Typical heat-sink heat-spreader configurations.

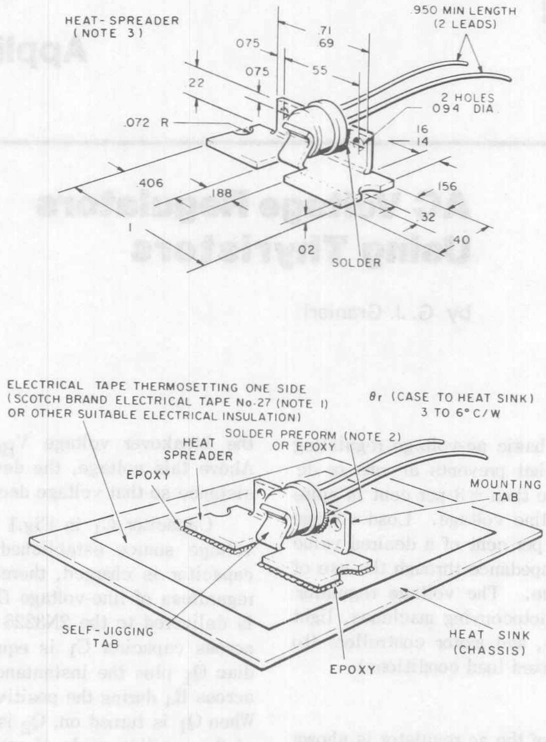


Fig.7 - Self-jigging heat spreader.

NOTES:

1. Products of Minnesota Mining & Mfg. Co., St. Paul, Minnesota.
2. Solder preforms are available from RCA as Part No.NR184A and from the Kester Solder Co., Newark, N.J. 07105 as Part No.KSFD-375005.
3. This heat spreader is available from RCA as Part No.NR166B and from the General Stamping Co., Inc. Denville, N.J. 07834 as Part No.14-110.

AC Voltage Regulators Using Thyristors

by G. J. Granieri

This Note describes a basic ac-voltage regulating technique using thyristors that prevents ac rms or dc voltage from fluctuating more than ± 3 per cent in spite of wide variations in input line voltage. Load voltage can also be held within ± 3 per cent of a desired value despite variations in load impedance through the use of a voltage-feedback technique. The voltage regulator described can be used in photocopying machines, light dimmers, dc power supplies, and motor controllers (to maintain fixed speed under fixed load conditions).

Circuit Operation

The schematic diagram of the ac regulator is shown in Fig.1. For simplicity, only a half-wave SCR configuration is shown; however, the explanation of circuit operation is easily extended to include a full-wave regulator that uses a triac.

The trigger device Q_1 used in Fig.1, a diac such as the RCA-D3202U, is an all-diffused three-layer trigger diode. This diac exhibits a high-impedance, low-leakage-current characteristic until the applied voltage reaches the breakover voltage V_{BO}, approximately 35 volts. Above this voltage, the device exhibits a negative resistance so that voltage decreases as current increases.

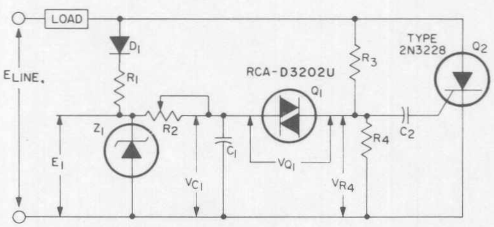


Fig.1 - A basic ac regulator.

Capacitor C_1 in Fig.1 is charged from a constant-voltage source established by zener diode Z_1. The capacitor is charged, therefore, at an exponential rate regardless of line-voltage fluctuations. A trigger pulse is delivered to the 2N3228 SCR, Q_2, when the voltage across capacitor C_1 is equal to the trigger voltage of diac Q_1 plus the instantaneous voltage drop developed across R_4 during the positive half-cycle of line voltage. When Q_1 is turned on, Q_2 is turned on for the remainder of the positive cycle of source voltage. Control of the conduction angle of the SCR regulates rms voltage to the load.

Regulation is achieved by the following means: When line voltage increases, the voltage across R_4 increases, but the charging rate of C_1 remains the same; as a result, the voltage across C_1 must attain a larger value than required without line-voltage increase before diac Q_1 can be triggered. The net effect is that the pulse that triggers Q_2 is delayed and the rms voltage to the load is reduced. In a similar manner, as line voltage is reduced, Q_2 turns on earlier in the cycle and increases the effective voltage across the load.

Fig.2 shows the voltage waveforms exhibited by the ac regulator at both high and low line voltage. The charging voltage for capacitor C_1, E_1, is equal to the zener voltage and remains constant up to the instant that the SCR is turned on. The capacitor voltage, V_{C1}, increases exponentially because the charging voltage E_1 is constant. The voltage across resistor R_4 conforms

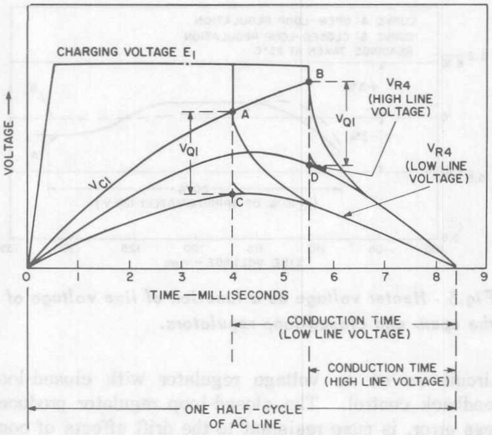


Fig.2 - Voltage waveforms exhibited by the ac regulator in Fig.1.

to the sinusoidal variations of the 60-Hz line voltage. At any given phase angle, the voltage across R_4 increases if line voltage increases and decreases if line voltage decreases.

The diac and SCR both trigger when the capacitor voltage, V_{C1}, equals the breakdown voltage of the diac plus the instantaneous value of voltage developed across R_4 during the positive half-cycle of line voltage. This capacitor voltage is represented by points A and B for the low and high line-voltage conditions, respectively. The instantaneous voltages across R_4 just before the SCR is triggered are represented by points C and D for the low and high line-voltage conditions, respectively. The voltage difference between points A and C and between points B and D is equal to the breakdown voltage of the diac.

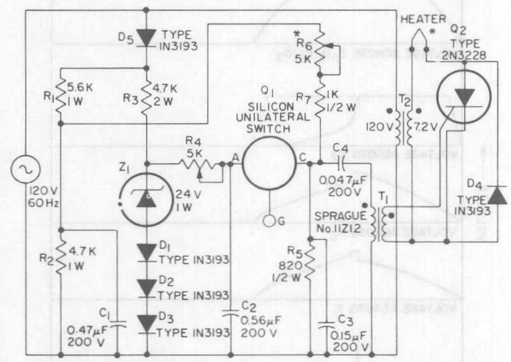
Fig.2 illustrates that the conduction time of the SCR is decreased as line voltage increases, and is increased when the line voltage decreases. By proper selection of the values of the voltage-divider-ratio resistors R_3 and R_4, it is possible to prevent the load voltage from varying more than 3 per cent with a 30-per-cent (approximate) change in line voltage.

It should be mentioned that during measurements of load voltage careful consideration must be given to the measuring instruments. Most of the circuits described in this Note produce a non-sinusoidal voltage across the load; the rms value of this voltage can be measured only with a true rms meter, such as a thermocouple meter. It is possible, however, that in certain applications the low input impedance of the thermocouple meter might load down the circuit being measured. In such cases, a high-input-impedance rms meter may be required.

HEATER REGULATION

Fig.3 shows a basic regulating technique for applications in which it is desired to maintain constant voltage across a load such as a receiving-tube heater, the filament of an incandescent lamp, or possibly a space heater. It should be noted that this configuration is actually a half-wave regulator. However, the circuit of Fig.3 differs from the circuit of Fig.1, in which one half-cycle is blocked from the load and the other half-cycle is phase-controlled to provide regulation. In Fig.3, essentially full voltage is applied to the load for one half-cycle by means of D4; the other half-cycle is phase-controlled by the SCR to provide regulation.

The circuit in Fig.3 is an open-loop regulator that features a high degree of safety; i.e., an open– or short-circuited component does not result in an excessive



* IN THE CLOSED-LOOP REGULATOR R_6 IS REPLACED BY A PHOTOCELL RCA SQ2520 AND A POTENTIOMETER IN SERIES WITH A 6-VOLT INCANDESCENT LAMP IS CONNECTED IN PARALLEL WITH THE HEATER TERMINALS
NOTE: ALL RESISTOR VALUES ARE IN OHMS

Fig.3 - A circuit using a regulator to maintain voltage constant across a load.

load voltage. Phase-controlled voltage regulation is provided by a silicon unilateral switch Q1* and a control circuit, as follows: Capacitor C_2 is charged from a voltage source that is maintained constant by zener diode Z_1; diodes D_1, D_2, and D_3 compensate for the change in zener voltage with temperature. The voltage across C_2 increases until the sum of the breakover voltage of Q_1 and the instantaneous voltage across R_5 is exceeded. At this point, a positive pulse is coupled into the gate of Q_2 by means of the pulse transformer T_1. The SCR Q_2 then switches on for the remainder of the positive cycle of line voltage. Control of the conduction angle of the SCR varies rms voltage to the heater.

* A silicon unilateral switch is a silicon, planar, monolithic integrated circuit that has thyristor electrical characteristics closely approximating those of an ideal four-layer diode. The device shown switches at approximately 8 volts.

As line voltage increases, the voltage across R_5 also increases; because C_2 charges along the same exponential curve, however, the voltage across C_2 must attain a larger value before Q_2 is turned on. The net effect is a delay in the trigger pulse and reduced rms voltage across the heater. In a similar manner, as line voltage is reduced, the SCR turns on earlier in the cycle and increases the effective voltage across the heater. By proper adjustment of potentiometer R_6 in conjunction with potentiometer R_4, it is possible to obtain excellent heater-voltage compensation over a range of line voltages. Fig.4 shows the waveforms associated with the heater-regulator circuit.

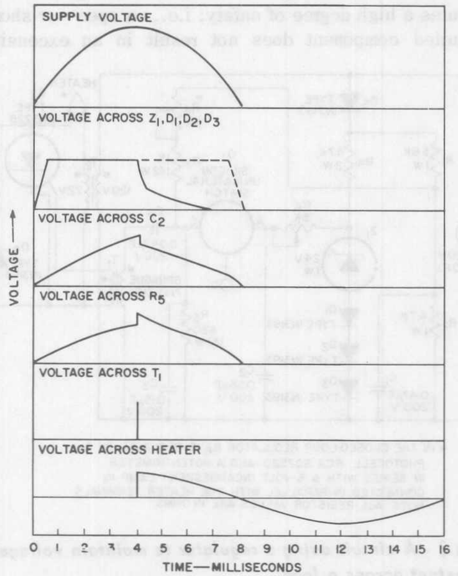


Fig.4 - Voltage waveforms exhibited by the circuit of Fig.3.

Curve A in Fig.5 shows heater voltage as a function of line voltage for the open-loop regulator circuit shown in Fig.3. Curve B in Fig.5 shows a similar curve for a closed-loop regulator using a lamp-photocell module. The lamp, in series with a limiting resistor, is connected across the heater terminals, and the photocell replaces R_6. The lamp unit senses the phase-controlled true rms heater voltage. Changes in lamp brightness produced by heater-voltage variations change the photocell resistance in reverse proportion to the lamp voltage. The remainder of the circuit functions as previously described except that regulation is obtained not only through the monitoring of the instantaneous magnitude of line voltage, but also through the sensing of the true rms voltage across the heater. This characteristic identifies the

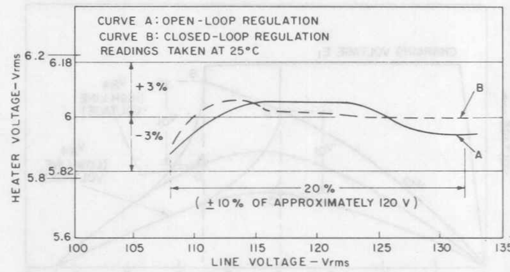


Fig.5 - Heater voltage as a function of line voltage of the open- and closed-loop regulators.

circuit as an ac voltage regulator with closed-loop feedback control. The closed-loop regulator produces less error, is more resistant to the drift effects of components, and is easier to adjust than the open-loop regulator.

The lamp used in the closed-loop regulator is rated at 6 volts, but the series resistor limits the voltage to approximately 2 volts so that extremely long lamp life can be expected. An additional advantage at low voltage is that the light intensity varies linearly with the voltage across the lamp so that a small increase in voltage increases brightness markedly; near rated voltage the intensity does not vary linearly and the variation in brightness is not very apparent. A loss in sensitivity would result if the lamp were operated at its rated voltage.

The open-loop regulator can regulate 6 volts to within ± 3 per cent within a temperature range from 10 to 40°C with an input-voltage swing of ± 10 per cent. The closed-loop regulator can regulate 6 volts to within ± 2 per cent within a temperature range from 0 to 60°C with an input-voltage swing of ± 10 per cent.

LIGHT DIMMER WITH OVER-VOLTAGE CLAMP

Light-dimmer circuits are becomingly increasingly popular for home use. Fig.6 shows a typical light-dimmer configuration. This circuit provides the advantages of low hysteresis and continuous control up to the maximum conduction angle. At low illumination

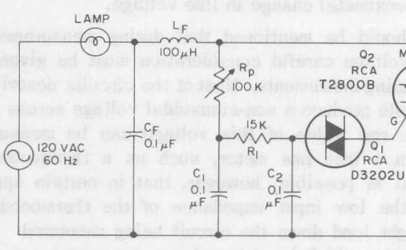


Fig.6 - A typical light-dimmer circuit.

levels, however, the variable resistor R_p is adjusted to a high resistance setting. If a momentary drop in line voltage occurs at this condition, the high breakover voltage of the diac in conjunction with the high resistance could result in a circuit misfire; i.e., the light could be extinguished and remain so until the circuit is reset by readjustment of the control to a high illumination setting.

A natural successor to the circuit of Fig.6 might consist of a configuration which not only provides the light-dimming function but also extends the life of the lamp being controlled. One of the major causes of reduced lamp life can be directly attributed to line-voltage fluctuations and in particular to periods of over-voltage. Nominal line voltage is approximately 120 volts ± 10 per cent; it is the + 10-per-cent variation that causes lamps to reach end-of-life prematurely.

A technique for limiting or clamping the lamp voltage, without sacrificing any of the desirable features of the dimmer of Fig.6, is shown in Fig.7; L_F and C_F suppress rf interference. Fig.7 employs the basic regulating circuit described earlier; however, in the configuration shown, the switching voltage of Q_1, a silicon bilateral switch,* is reduced by steering diodes D_1 and D_2 in conjunction with resistor R. This arrangement not

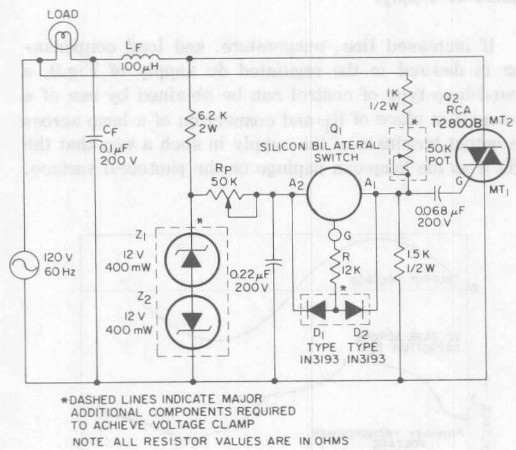


Fig.7 - A light-dimmer circuit that includes clamping.

only makes it possible to achieve larger conduction angles, but also prevents the circuit from misfiring at low illumination levels when it is subjected to dips in line voltage. The light-dimmer circuit in Fig.7 is capable of clamping the high-line-voltage condition to within +3 per cent of its nominal value; as a result, the lamp is subjected to voltages of 120 volts plus 3 per cent and minus 10 per cent. The − 10-per-cent line dip has little effect on lamp-life reduction.

The circuit also regulates lamp voltage for various settings of potentiometer R_p. Fig.8 shows line voltage as a function of lamp voltage for two settings of R_p for the circuits of Figs.6 and 7. These curves illustrate the increased regulation achieved by the improved circuit.

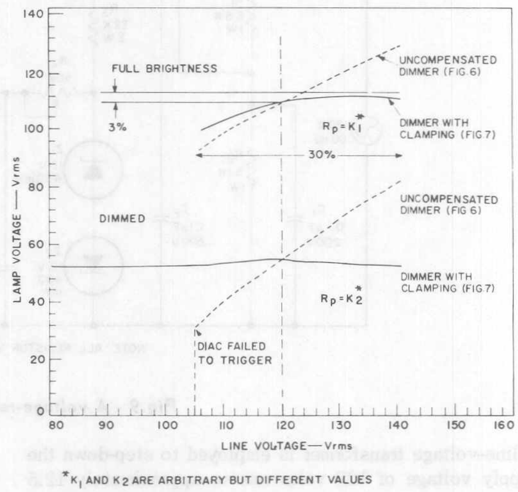


Fig.8 - Lamp voltage as a function of line voltage for two values of R_p in the circuits of Figs.6 and 7.

The dimmer configuration of Fig.7 can also be used as a 120-volt full-wave heater regulator. In this application the light is replaced by a heater load. If the load can be operated at a nominal 100 volts with an input voltage of 120 volts, more symmetrical regulation can be realized; i.e., ±3 per cent regulation can be achieved with a line variation of ±10 per cent. In the full-wave heater-regulator application, diodes D_1, D_2, and resistor R in Fig.7 can be eliminated because a wide conduction angle is not required.

Such a control might also be used in colorimetry, an application in which it is necessary to match the color (and temperature) of a lamp with a standard; in this application line-voltage fluctuations can create a measurement error. Other areas of application, such as photography, heater control, and hot-plate and solder-pot control, can also make effective use of the dimmer circuit with over-voltage clamp.

VOLTAGE-REGULATED DC SUPPLY

A simple but stable dc power supply using thyristors is shown in Fig.9. The power-supply section consists of the well known full-wave bridge with RC filter.

* A silicon bilateral switch is a silicon, planar, monolithic integrated circuit that switches at approximately 8 volts in both directions.

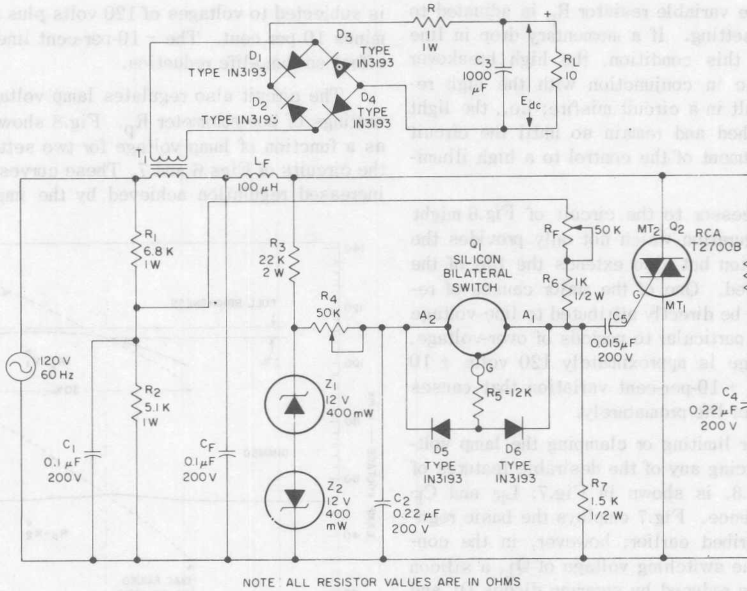


Fig.9 - A voltage-regulated dc supply.

A line-voltage transformer is employed to step-down the supply voltage of 120 volts rms to approximately 12.5 volts rms. If a dc output voltage greater than 10 volts is desired, a transformer with a lower primary-to-secondary turns ratio should be employed.

The heart of the regulator shown in Fig.9 is the phase-controlled triac on the primary side of the line transformer. Because the load presented to the triac is somewhat inductive, an RC network is used to assure proper commutation; L_F and C_F suppress rf interference. The circuit automatically compensates for wide variations in line voltage. Fig.10 shows a curve of line voltage as a function of load voltage, E_{dc}, for a constant load of 10 ohms. Fig.11 shows the voltage waveforms associated with the circuit of Fig.9.

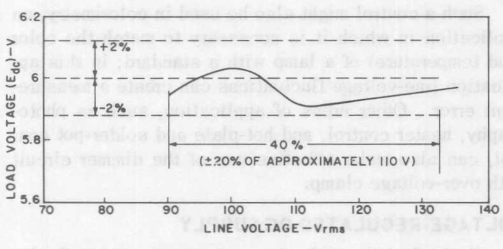


Fig.10 - Load voltage as a function of line voltage for the circuit of Fig.9; load resistance is constant at 10 ohms.

If increased line, temperature, and load compensation is desired in the regulated dc supply of Fig.9, a closed-loop type of control can be obtained by use of a photocell in place of R_F and connection of a lamp across the output terminals of the supply in such a way that the light from the lamp can impinge on the photocell surface.

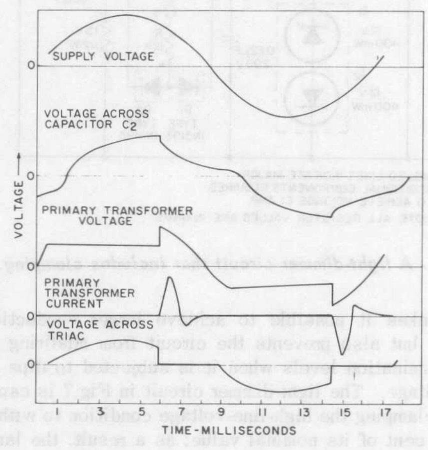


Fig.11 - Voltage waveforms exhibited by the circuit of Fig.9.

SELECTION OF CONTROL DEVICE

Other thyristors than those shown in this Note can also be used for voltage regulation. The selection of an SCR or triac for a particular regulating circuit depends on the voltage and current requirements of the application. The quick-selection charts shown below indicate the capabilities of RCA thyristors for this type of usage.

	Triac Quick-Selection Chart						SCR Quick-Selection Chart					
	0.35A	6A	10A	15A	30A	40A	2A	5A	12.5A	15A	25A	35A
120-Volt Line Operation	T2300B	T2700B	2N5567	2N5571	T6401B	2N5441	2N3528	2N3228	2N3669	2N1846A	1N685	2N3871
	T2302B	T2710B	2N5569	2N5573	T6411B	2N5444		S2710B				2N3897
	T2310B			T4700B				S3700B				
	T2312B											
240-Volt Line Operation	T2300D	T2700D	2N5568	2N5572	T6401D	2N5442	2N3529	2N3525	2N3670	2N1849A	2N688	2N3872
	T2302D	T2710D	2N5570	2N5574	T6411D	2N5445		S2710D				2N3898
	T2310D			T4700D				S3700D				
	T2312D											

Handling and Mounting of RCA Molded-Plastic Transistors and Thyristors

by W.J. Hepp, J.S. Vara, and J. Gaylord

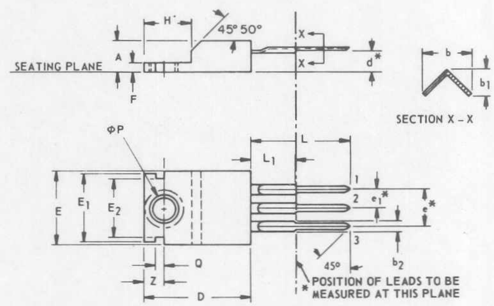
RCA power transistors and thyristors (SCR's and triacs) in molded-silicone-plastic packages are available in a wide range of power-dissipation ratings and a variety of package configurations. This Note provides detailed guidelines for handling and mounting of these plastic-package devices, and shows different types of packages and suggested mounting hardware to accommodate various mounting arrangements. Recommendations are made for handling of the packages during the forming of leads to meet specific mounting requirements. Various mounting arrangements, thermal considerations, and cleaning methods are described. This information is intended to augment the data on electrical characteristics, safe operating area, and performance capabilities in the technical bulletin for each type of plastic-package transistor or thyristor. (Data on mechanical and environmental capabilities of RCA plastic-package transistors are also available in a periodically updated **Reliability Report**, RCA Publication No. HBT-600.)

TYPES OF PACKAGES

Two basic types of molded-plastic packages are used for RCA solid-state power devices. These types include the RCA Versawatt packages for medium-power applications and the RCA high-power plastic packages, both of which are specifically designed for ease of use in many applications. Each basic type offers several different package options, and the user can select the configuration best suited to his particular application.

Figs. 1 through 3 show the options currently available for devices in RCA Versawatt packages. The JEDEC Type TO-220AB in-line-lead version, shown in Fig. 1, represents the basic style. This configuration features leads that can be formed to meet a variety of specific mounting requirements. Fig. 2 shows a package configuration that allows a Versawatt package to be mounted on a printed-circuit board with a 0.100-inch grid and a minimum lead spacing of 0.200 inch. Fig. 3 shows a JEDEC Type TO-220AA version of the Versawatt package. The dimensions of this type of transistor package are such that it can replace the JEDEC TO-66 transistor package in a commercial socket or printed-circuit board without retooling. The pin-connection arrangement of thyristors supplied in TO-220AA packages, however, differs from that of thyristors supplied in conventional TO-66 packages so that some hardware changes are required to effect a replacement. The TO-220AA Versawatt package is also supplied with an integral heat sink. Fig. 4 shows the dimensional outline for this heat sink. The use of the integral heat sink reduces the junction-to-air thermal resistance of the package from 70°C per watt to 35°C per watt.

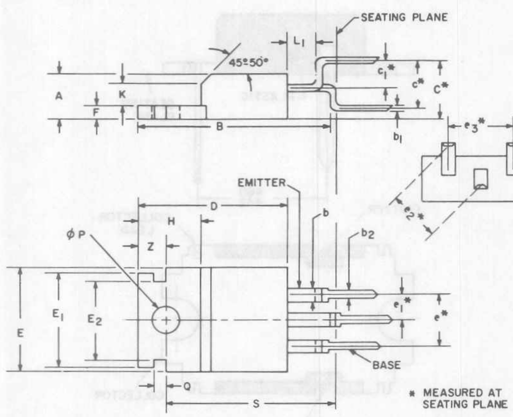
The RCA molded-plastic high-power packages are also supplied in several configurations for flexibility of application. The JEDEC Type TO-219AB, shown in Fig. 5, is the basic high-power plastic package. Fig. 6 shows a JEDEC Type TO-219AA version of the high-power plastic package.



SYMBOL	INCHES MIN.	INCHES MAX.
A	.140	.190
b	.020	.038
b_1	.012	.045
b_2	.045	.070
D	.560	.625
d	.080	.115
E	.330	.420
E_1	.365	.385
E_2	.300	.320

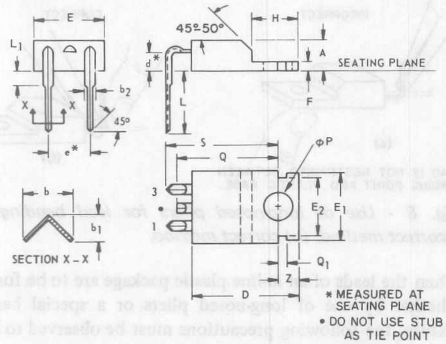
SYMBOL	INCHES MIN.	INCHES MAX.
e	.190	.210
e_1	.090	.110
F	.045	.055
H	.230	.270
L	.500	.562
L_1		.250
ΦP	.139	.147
Q	.040	.060
Z	.100	.120

Fig. 1 - Dimensional outline of the JEDEC TO-220AB in-line-lead Versawatt transistor package.



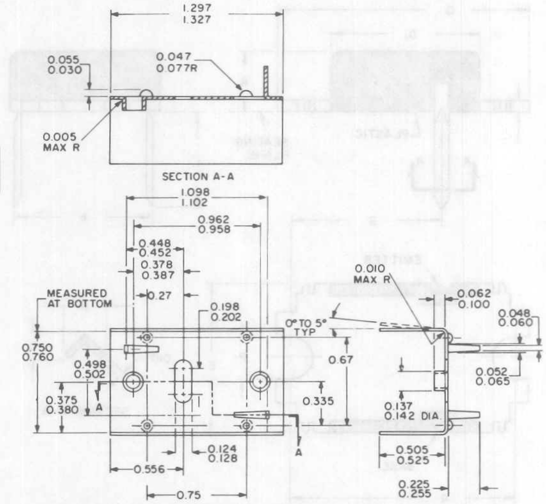
SYMBOL	INCHES MIN.	MAX	SYMBOL	INCHES MIN.	MAX
A	.140	.190	e	.190	.210
B		.850	e_1	.090	.110
b	.045	.070	e_2	.203	.243
b_1	.015	.030	e_3	.190	.200
b_2	.020	.038	F	.045	.070
C	.230	.270	H	.230	.270
c	.180	.220	K	.080	.085
c_1	.130	.170	L_1	.070	.090
D	.560	.625	ϕP	.139	.147
E	.330	.410	Q	.040	.060
E_1	.365	.385	S	.655	.685
E_2	.300	.320	Z	.100	.120

Fig. 2 - Dimensional outline of Versawatt transistor package designed for mounting on printed-circuit boards.



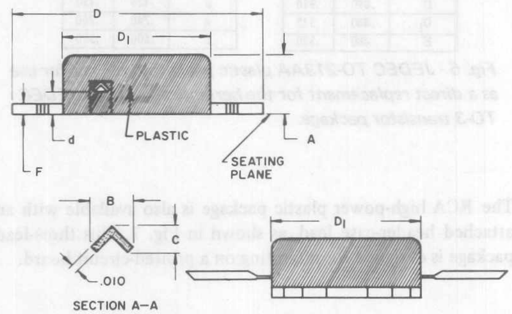
SYMBOL	INCHES MIN.	MAX.	SYMBOL	INCHES MIN.	MAX.
A	.140	.190	F	.045	.055
b	.020	.038	H	.230	.270
b_1	.012	.045	L	.360	.422
b_2	.045	.070	L_1		.050
D	.560	.625	ϕP	.139	.147
d	.080	.115	q		.610
E	.330	.420	Q_1	.040	.060
E_1	.365	.385	S	.580	.610
E_2	.300	.320	Z	.100	.120
e	.190	.210			

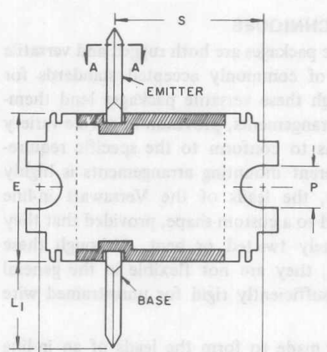
Fig. 3 JEDEC TO-220AA Versawatt transistor package designed for direct replacement of the JEDEC TO-66 package.



ALL DIMENSIONS ARE IN INCHES UNLESS OTHERWISE SHOWN. TOLERANCES ARE: ±0.02 FOR 2ND PLACE; ±0.005 FOR 3RD PLACE AND ±1/2° FOR ANGULAR DIMENSION.

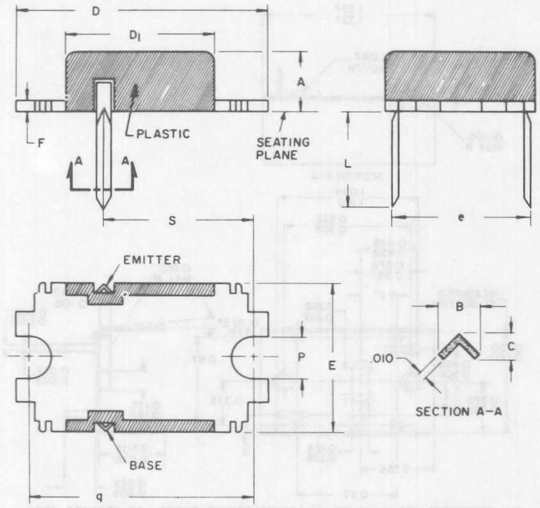
Fig. 4 Integral heat sink used with the TO-220AA Versawatt package shown in Fig. 3.





SYMBOL	INCHES MIN.	MAX.
A	.160	.200
B	.045	.060
C	.025	.045
D	.890	.910
D_1	.480	.515
d	.100	.120
E	.480	.520
F	.055	.070
L_1	.415	.560
P	.128	.150
q	.740	.760
S	.500	.520

Fig. 5 - JEDEC TO-219AB high-power molded-plastic transistor package.



SYMBOL	INCHES		SYMBOL	INCHES	
	MIN.	MAX.		MIN.	MAX.
A	.160	.200	e	.460	.505
B	.045	.060	F	.055	.070
C	.025	.045	L	.370	.450
D	.890	.910	p	.128	.150
D_1	.480	.515	q	.740	.760
E	.480	.520	S	.500	.520

Fig. 6 - JEDEC TO-219AA plastic package designed for use as a direct replacement for the hermetically sealed JEDEC TO-3 transistor package.

The RCA high-power plastic package is also available with an attached header-case lead, as shown in Fig. 7. This three-lead package is designed for mounting on a printed-circuit board.

LEAD-FORMING TECHNIQUES

RCA Versawatt plastic packages are both rugged and versatile within the confines of commonly accepted standards for such devices. Although these versatile packages lend themselves to numerous arrangements, provision of a wide variety of lead configurations to conform to the specific requirements of many different mounting arrangements is highly impractical. However, the leads of the Versawatt in-line package can be formed to a custom shape, provided that they are not indiscriminately twisted or bent. Although these leads can be formed, they are not flexible in the general sense, nor are they sufficiently rigid for unrestrained wire wrapping.

Before an attempt is made to form the leads of an in-line package to meet the requirements of a specific application, the desired lead configuration should be determined, and a lead-bending fixture should be designed and constructed. The

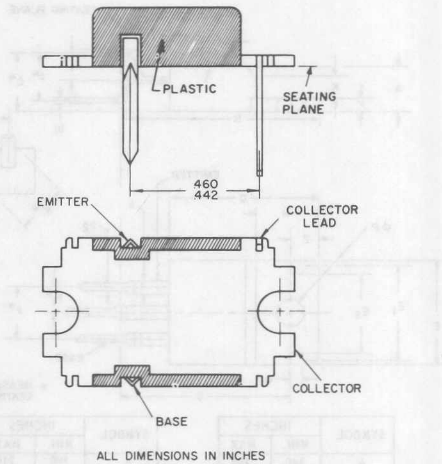


Fig. 7 - TO-219AA plastic transistor package designed for mounting on printed-circuit boards.

use of a properly designed fixture for this operation eliminates the need for repeated lead bending. When the use of a special bending fixture is not practical, a pair of long-nosed pliers may be used. The pliers should hold the lead firmly between the bending point and the case, but should not touch the case. Fig. 8 illustrates the use of long-nosed pliers for lead bending. Fig. 8(a) shows techniques that should be avoided; Fig. 8(b) shows the correct method.

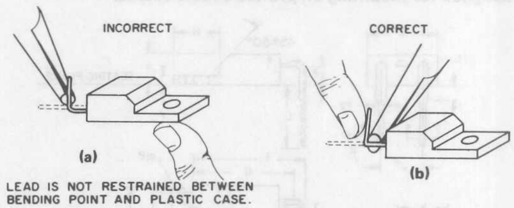


Fig. 8 - Use of long-nosed pliers for lead bending: (a) incorrect method; (b) correct method.

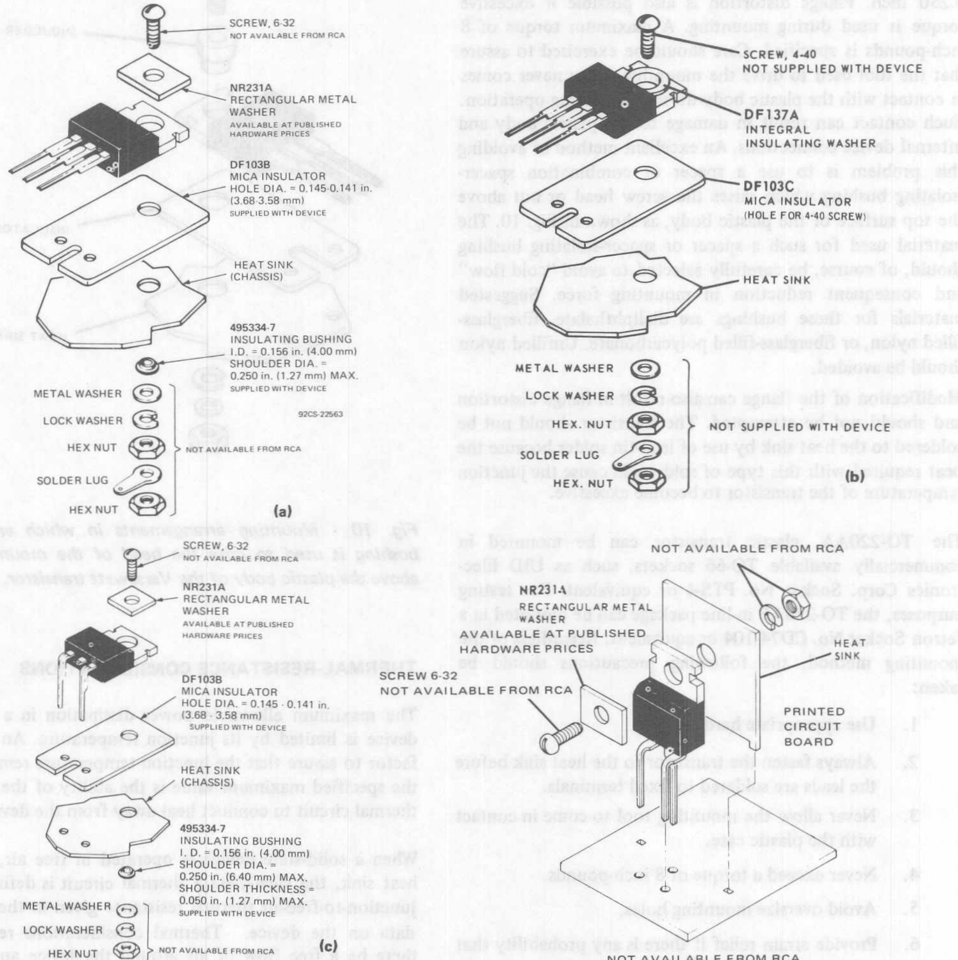
When the leads of an in-line plastic package are to be formed, whether by use of long-nosed pliers or a special bending fixture, the following precautions must be observed to avoid internal damage to the device:

1. Restrain the lead between the bending point and the plastic case to prevent relative movement between the lead and the case.
2. When the bend is made in the plane of the lead (spreading), bend only the narrow part of the lead.
3. When the bend is made in the plane perpendicular to that of the leads, make the bend at least 1/8 inch from the plastic case.
4. Do not use a lead-bend radius of less than 1/16 inch.
5. Avoid repeated bending of leads.

The leads of the TO-220AB Versawatt in-line package are not designed to withstand excessive axial pull. Force in this direction greater than 4 pounds may result in permanent damage to the device. If the mounting arrangement tends to impose axial stress on the leads, some method of strain relief should be devised. Fig. 2 illustrates an acceptable lead-forming method that provides this relief.

Wire wrapping of the leads is permissible, provided that the lead is restrained between the plastic case and the point of the wrapping. Soldering to the leads is also allowed; the maximum soldering temperature, however, must not exceed 275°C and must be applied for not more than 5 seconds at a distance greater than 1/8 inch from the plastic case. When wires are used for connections, care should be exercised to assure that movement of the wire does not cause movement of the lead at the lead-to-plastic junctions.

The leads of the RCA molded-plastic high-power packages are not designed to be reshaped. Simple bending of the leads, however, is permitted to change them from a standard vertical to a standard horizontal configuration, or conversely. Bending of the leads in this manner is restricted to three 90-degree bends; repeated bendings, therefore, should be avoided.



In the United Kingdom, Europe, Middle East, and Africa, mounting-hardware policies may differ; check the availability of all items shown with your RCA sales representative or supplier.

Fig. 9 - Mounting arrangements for Versawatt transistors: (a) and (b) methods of mounting in-line-lead types; (c) chassis mounting; (d) mounting on printed-circuit boards.

MOUNTING

Fig. 9 shows recommended mounting arrangements and suggested hardware for the Versawatt transistors. The rectangular washer (NR231A) shown in Fig. 9(a) is designed to minimize distortion of the mounting flange when the transistor is fastened to a heat sink. Excessive distortion of the flange could cause damage to the transistor. The washer is particularly important when the size of the mounting hole exceeds 0.140 inch (6-32 clearance). Larger holes are needed to accommodate insulating bushings; however, the holes should not be larger than necessary to provide hardware clearance and, in any case, should not exceed a diameter of 0.250 inch. Flange distortion is also possible if excessive torque is used during mounting. A maximum torque of 8 inch-pounds is specified. Care should be exercised to assure that the tool used to drive the mounting screw never comes in contact with the plastic body during the driving operation. Such contact can result in damage to the plastic body and internal device connections. An excellent method of avoiding this problem is to use a spacer or combination spacer-isolating bushing which raises the screw head or nut above the top surface of the plastic body, as shown in Fig. 10. The material used for such a spacer or spacer-isolating bushing should, of course, be carefully selected to avoid "cold flow" and consequent reduction in mounting force. Suggested materials for these bushings are diallphthalate, fiberglass-filled nylon, or fiberglass-filled polycarbonate. Unfilled nylon should be avoided.

Modification of the flange can also result in flange distortion and should not be attempted. The transistor should not be soldered to the heat sink by use of lead-tin solder because the heat required with this type of solder will cause the junction temperature of the transistor to become excessive.

The TO-220AA plastic transistor can be mounted in commercially available TO-66 sockets, such as UID Electronics Corp. Socket No. PTS-4 or equivalent. For testing purposes, the TO-220AB in-line package can be mounted in a Jetron Socket No. CD74-104 or equivalent. Regardless of the mounting method, the following precautions should be taken:

1. Use appropriate hardware.
2. Always fasten the transistor to the heat sink before the leads are soldered to fixed terminals.
3. Never allow the mounting tool to come in contact with the plastic case.
4. Never exceed a torque of 8 inch-pounds.
5. Avoid oversize mounting holes.
6. Provide strain relief if there is any probability that axial stress will be applied to the leads.
7. Use insulating bushings to prevent hot-creep problems. Such bushings should be made of diallphthalate, fiberglass-filled nylon, or fiberglass-filled polycarbonate.

Fig. 11 shows the recommended hardware and mounting arrangements for RCA high-power molded-plastic transistors. These types can be mounted directly in a socket similar to that shown in Fig. 11(b). The precautions listed for the Versawatt packages should also be followed in the mounting of the high-power molded-plastic packages.

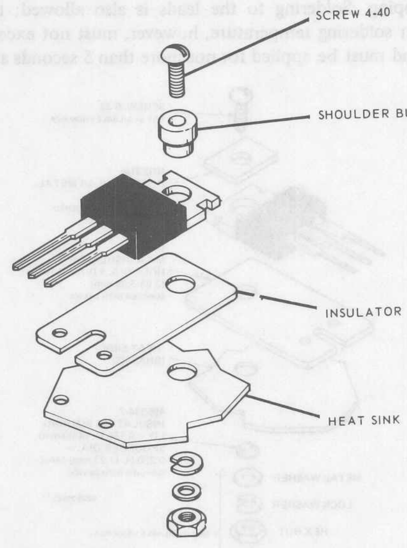


Fig. 10 - Mounting arrangements in which an isolating bushing is used to raise the head of the mounting screw above the plastic body of the Versawatt transistor.

THERMAL-RESISTANCE CONSIDERATIONS

The maximum allowable power dissipation in a solid-state device is limited by its junction temperature. An important factor to assure that the junction temperature remains below the specified maximum value is the ability of the associated thermal circuit to conduct heat away from the device.

When a solid-state device is operated in free air, without a heat sink, the steady-state thermal circuit is defined by the junction-to-free-air thermal resistance given in the published data on the device. Thermal considerations require that there be a free flow of air around the device and that the power dissipation be maintained below that which would cause the junction temperature to rise above the maximum rating. When the device is mounted on a heat sink, however, care must be taken to assure that all portions of the thermal circuit are considered.

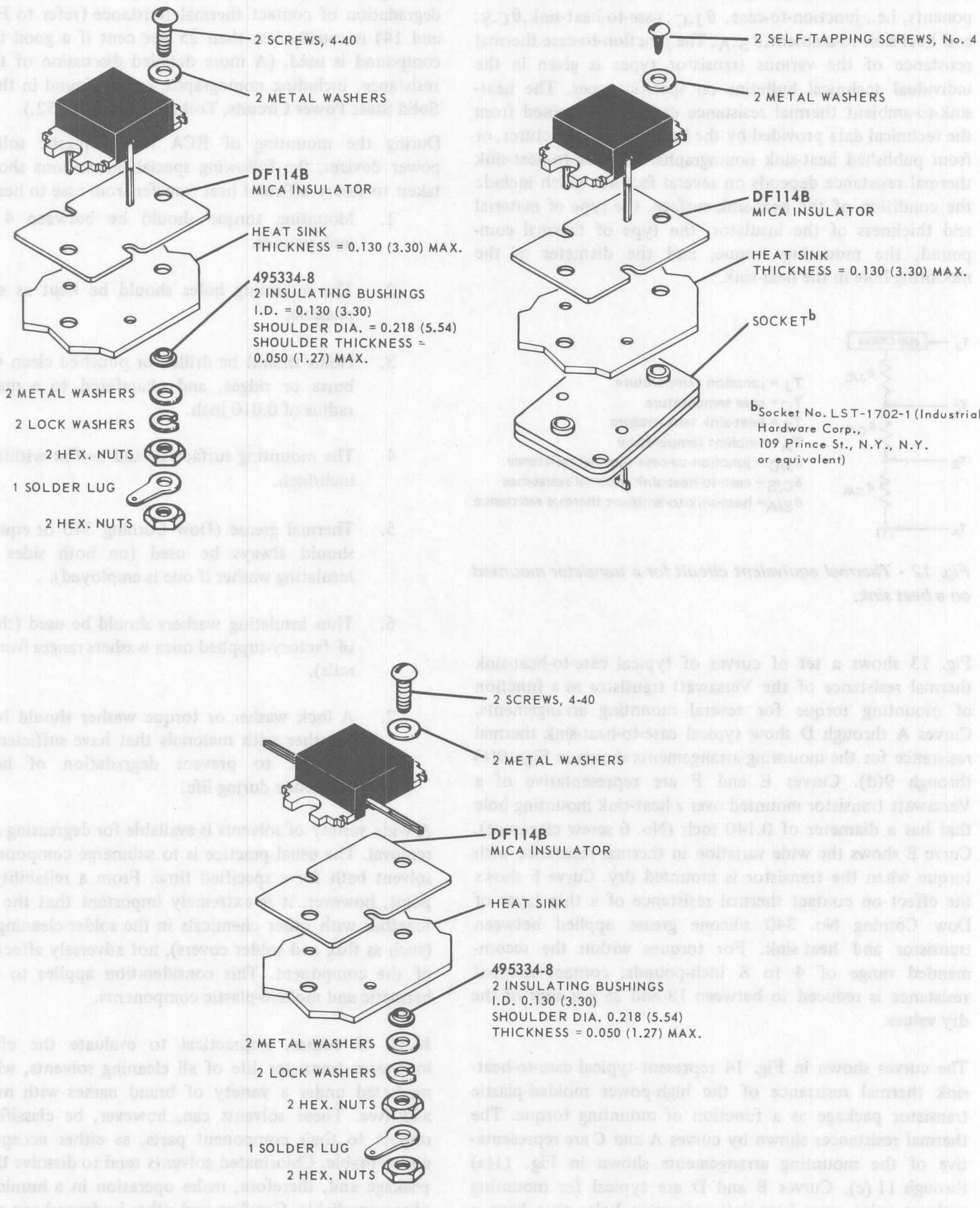


Fig. 11 - Mounting arrangements for high-power plastic-package transistors: (a) chassis mounting; (b) socket mounting; (c) printed-circuit-board mounting.

Fig. 12 shows the thermal circuit for a heat-sink-mounted transistor. This figure shows that the junction-to-ambient thermal circuit includes three series thermal-resistance components, i.e., junction-to-case, $\theta_{J\text{-}C}$; case-to-heat-sink, $\theta_{C\text{-}S}$; and heat-sink-to-ambient, $\theta_{S\text{-}A}$. The junction-to-case thermal resistance of the various transistor types is given in the individual technical bulletins on specific types. The heat-sink-to-ambient thermal resistance can be determined from the technical data provided by the heat-sink manufacturer, or from published heat-sink nomographs. The case-to-heat-sink thermal resistance depends on several factors, which include the condition of the heat-sink surface, the type of material and thickness of the insulator, the type of thermal compound, the mounting torque, and the diameter of the mounting hole in the heat-sink.

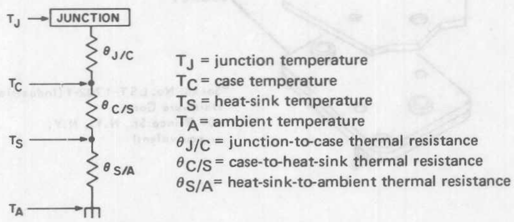


Fig. 12 - Thermal equivalent circuit for a transistor mounted on a heat sink.

Fig. 13 shows a set of curves of typical case-to-heat-sink thermal resistance of the Versawatt transistor as a function of mounting torque for several mounting arrangements. Curves A through D show typical case-to-heat-sink thermal resistance for the mounting arrangements shown in Figs. 9(a) through 9(d). Curves E and F are representative of a Versawatt transistor mounted over a heat-sink mounting hole that has a diameter of 0.140 inch (No. 6 screw clearance). Curve E shows the wide variation in thermal resistance with torque when the transistor is mounted dry. Curve F shows the effect on contact thermal resistance of a thin layer of Dow Corning No. 340 silicone grease applied between transistor and heat sink. For torques within the recommended range of 4 to 8 inch-pounds, contact thermal resistance is reduced to between 18 and 25 per cent of the dry values.

The curves shown in Fig. 14 represent typical case-to-heat-sink thermal resistance of the high-power molded-plastic transistor package as a function of mounting torque. The thermal resistances shown by curves A and C are representative of the mounting arrangements shown in Fig. 11(a) through 11 (c). Curves B and D are typical for mounting without mica over heat-sink mounting holes that have a diameter of 0.113 inch (No. 4 screw clearance). The effect of a thin layer of silicone grease on contact thermal resistance is illustrated by a comparison of curves B and D.

Operation of the transistor with heat-sink temperatures of $100^{o}C$ or greater results in some shrinkage of the insulating bushing normally used to mount power transistors. The degradation of contact thermal resistance (refer to Figs. 13 and 14) is usually less than 25 per cent if a good thermal compound is used. (A more detailed discussion of thermal resistance, including nomographs, can be found in the **RCA Solid State Power Circuits**, Technical Series SP-52.)

During the mounting of RCA molded-plastic solid-state power devices, the following special precautions should be taken to assure efficient heat transfer from case to heat sink:

1. Mounting torque should be between 4 and 8 inch-pounds.

2. The mounting holes should be kept as small as possible.

3. Holes should be drilled or punched clean with no burrs or ridges, and chamfered to a maximum radius of 0.010 inch.

4. The mounting surface should be flat within 0.002 inch/inch.

5. Thermal grease (Dow Corning 340 or equivalent) should always be used (on both sides of the insulating washer if one is employed).

6. Thin insulating washers should be used (thickness of factory-supplied mica washers ranges from 2 to 4 mils).

7. A lock washer or torque washer should be used, together with materials that have sufficient creep strength to prevent degradation of heat-sink efficiency during life.

A wide variety of solvents is available for degreasing and flux removal. The usual practice is to submerge components in a solvent bath for a specified time. From a reliability standpoint, however, it is extremely important that the solvent, together with other chemicals in the solder-cleaning system (such as flux and solder covers), not adversely affect the life of the component. This consideration applies to all non-hermetic and molded-plastic components.

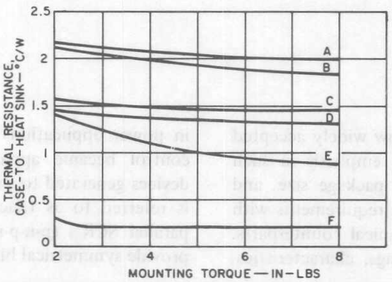
It is, of course, impractical to evaluate the effect on long-term transistor life of all cleaning solvents, which are marketed under a variety of brand names with numerous additives. These solvents can, however, be classified with respect to their component parts, as either acceptable or unacceptable. Chlorinated solvents tend to dissolve the outer package and, therefore, make operation in a humid atmosphere unreliable. Gasoline and other hydrocarbons cause the inner encapsulant to swell and damage the transistor. Alcohol and unchlorinated freons are acceptable solvents. Examples of such solvents are:

1. Freon TE
2. Freon TE-35
3. Freon TP-35 (Freon PC)
4. Alcohol (isopropanol, methanol, and special denatured alcohols, such as SDA1, SDA30, SDA34, and SDA44)

Care must also be used in the selection of fluxes in the soldering of leads. Rosin or activated rosin fluxes are recommended, while organic or acid fluxes are not. Examples of acceptable fluxes are:

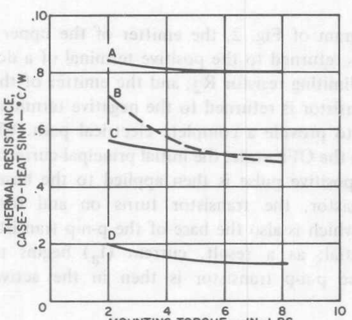
1. Alpha Reliaros No. 320-33
2. Alpha Reliaros No. 346
3. Alpha Reliaros No. 711
4. Alpha Reliafoam No. 807
5. Alpha Reliafoam No. 809
6. Alpha Reliafoam No. 811-13
7. Alpha Reliafoam No. 815-35
8. Kester No. 44

If the completed assembly is to be encapsulated, the effect on the molded-plastic transistor must be studied from both a chemical and a physical standpoint.



CURVE	MOUNTING ARRANGEMENT FIGURE	HEAT SINK HOLE DIA. (IN.)	MICA THICKNESS (MILS)	THERMAL COMPOUND
A	9(a)	.250	4	Dow Corning No.340
B	9(b)	.113	4	Dow Corning No.340
C	9(a)	.250	2	Dow Corning No.340
D	9(b)	.113	2	Dow Corning No.340
E		.140	None	None
F		.140	None	Dow Corning No.340

Fig. 13 Typical case-to-heat-sink thermal resistance as a function of mounting torque for an RCA Versawatt transistor.



CURVE	MOUNTING ARRANGEMENT FIGURE	MICA THICKNESS (MILS)	THERMAL COMPOUND
A	11(a) thru 11(c)	4	Dow Corning No.340
B	—	None	None
C	11(a) thru 11(c)	2	Dow Corning No.340
D	—	None	Dow Corning No.340

Fig. 14 - Typical case-to-heat thermal resistance as a function of mounting torque for an RCA high-power plastic-package transistor.

RCA Solid State Division

Thyristors Application Note AN-4242

A Review of Thyristor Characteristics and Applications

by T.C. McNulty

Thyristors, both SCR's and triacs, are now widely accepted in power-control applications. With the emphasis in such applications placed on low cost, small package size, and circuit simplicity, thyristors satisfy these requirements with reliability exceeding that of electromechanical counterparts. This Note describes the operation, ratings, characteristics, and typical applications of these devices.

Types of Thyristors

Thyristors are semiconductor devices that have characteristics similar to those of thyratron tubes; more specifically, they are semiconductor switches whose bistable state depends on the regenerative feedback associated with a p-n-p-n structure. Basically, this group includes any bistable semiconductor device that has three or more junctions (i.e., four or more semiconductor layers) and can be switched from a high-impedance (OFF) state to a conducting (ON) state, and from the conducting (ON) state to the high-impedance (OFF) state, within at least one quadrant of the principal-voltage characteristics.

There are several types of thyristors, which differ primarily in number of electrode terminals and operating characteristics associated with the third quadrant (negative) of the voltage-current characteristics. Reverse-blocking triode thyristors, commonly called silicon controlled rectifiers (SCR's), and bidirectional triode thyristors, referred to as triacs, are the most popular types. Silicon controlled rectifiers have satisfied the requirements of many power-switching applications with much greater reliability than electromechanical or tube counterparts. As the use of SCR's in power applications increased, the need for complete ac control became apparent. The new family of thyristor devices generated to provide bidirectional current properties is referred to as triacs. A triac can be considered as two parallel SCR's (p-n-p-n) oriented in opposite directions to provide symmetrical bidirectional characteristics.

Two-Transistor Analogy

The bistable action of thyristors can be explained by analysis of the structure of an SCR. This analysis can be related to either operating quadrant of a triac because a triac is essentially two parallel SCR's oriented in opposite directions. A two-transistor analogy of an SCR is illustrated in Fig. 1. Fig. 1(a) shows the schematic symbol for an SCR, and Fig. 1(b) shows the p-n-p-n structure the symbol represents. In the two-transistor model for the SCR shown in Fig. 1(c), the interconnections of the two transistors are such that regenerative action can occur when a proper gate signal is applied to the base of the lower n-p-n transistor.

In the diagram of Fig. 2, the emitter of the upper (p-n-p) transistor is returned to the positive terminal of a dc supply through a limiting resistor R_2, and the emitter of the lower (n-p-n) transistor is returned to the negative terminal of the dc supply to provide a complete electrical path. When the model is in the OFF state, the initial principal-current flow is zero. If a positive pulse is then applied to the base of the n-p-n transistor, the transistor turns on and forces the collector (which is also the base of the p-n-p transistor) to a low potential; as a result, current (I_a) begins to flow. Because the p-n-p transistor is then in the active state,

collector current ($I_{c1} = I_{b2}$) flows into the base of the n-p-n transistor and sets up the conditions for regeneration. If the external gate drive is removed, the model remains in the ON state as a result of the division of currents associated with the two transistors, provided that sufficient principal current (I_a) is available.

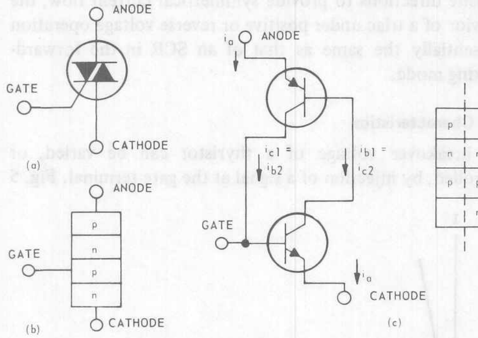


Fig. 1 - Two-transistor analogy of an SCR: (a) schematic symbol of SCR; (b) p-n-p-n structure represented by schematic symbol; (c) two-transistor model of SCR.

Theoretically, the model shown in Fig. 2 remains in the ON state until the principal current flow is reduced to zero. Actually, turn-off occurs at some value of current greater than zero. This effect can be explained by observation of the division of currents as the value of the limiting resistor is gradually increased. As the principal current is gradually reduced to the zero current level, the division of currents within the model can no longer sustain the required regeneration and the model reverts to the blocking state.

The two-transistor model illustrates three features of thyristors: (1) a gate trigger current is required to initiate regeneration, (2) a minimum principal current (referred to as "latching current") must be available to sustain regeneration, and (3) reduction of principal-current flow results in turn-off at some level of current flow (referred to as "holding current") slightly greater than zero.

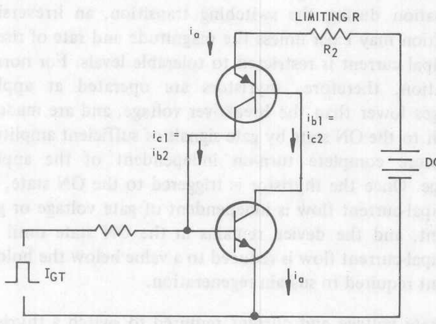


Fig.2 - Two-transistor model connected to show a complete electrical path.

Fig. 3 illustrates the effects on latching and holding current for resistive termination at the base of the n-p-n transistor. The collector current through the p-n-p transistor must be increased to supply both the base current for the n-p-n transistor and the shunt current through the terminating resistor. Because the principal-current flow must be increased to supply this increased collector current, latching and holding current requirements also increase. The use of the two-transistor model provides a more concise meaning to the mechanics of thyristors. In thyristor fabrication, it is generally good practice to use a low-beta p-n-p unit and to include internal resistance termination for the base of the n-p-n unit. Termination of the n-p-n unit provides immunity from "false" (non-gated) turn-on, and the use of the low-beta p-n-p units permits a wider base region to be used to support the high voltage encountered in thyristor applications.

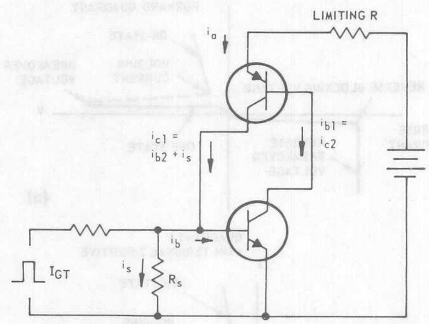


Fig.3 - Two-transistor model of SCR with resistive termination of the n-p-n transistor base.

Voltage and Temperature Ratings

The effects of temperature and voltage are important in thyristors because these devices possess regenerative action and are required to support high voltage in the OFF state. In the two-transistor model shown in Fig. 2, an increase in temperature causes a leakage current which, if allowed to migrate to the base of the n-p-n transistors, forces the transistor into the active region. Regenerative action then calls for additional leakage current, and causes the model to switch into the ON state and establish a principal-current flow. For reliable operation at high temperature, the base of the n-p-n transistor should be terminated with a low value of resistance to prevent turn-on as a result of high-temperature operation.

Because gate termination is required on all thyristors, RCA devices contain a diffused internal gate-cathode resistor (the so-called "shorted-emitter" design) and do not require external gate termination. Therefore, it is not necessary to specify an OFF-state rating under the conditions of external gate-resistance termination. The use of this internal shunt resistance improves the OFF-state blocking capability, provides increased immunity against false turn-on, and slightly increases gate-current requirements.

OFF-state voltage ratings of thyristors are specified for both steady-state and transient operation for both forward (positive) and reverse (negative) blocking conditions at the maximum junction temperature. For SCR's, voltages are considered to be forward (positive) when the anode is at a positive potential with reference to the cathode. Negative voltages are referred to as reverse-blocking voltages. For triacs, voltages are considered to be positive when main terminal 2 is at a positive potential with reference to main terminal 1; this condition is referred to as first-quadrant (I) operation. Third-quadrant (III) operation occurs when main terminal 2 is at a negative potential with reference to main terminal 1. Fig. 4 shows the principal voltage-current characteristics for both SCR's and triacs.

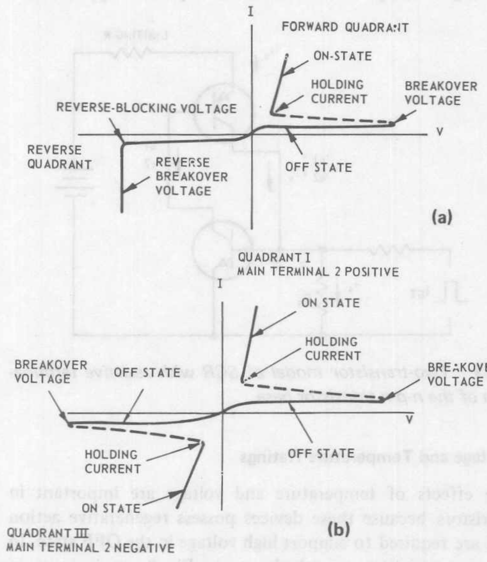


Fig.4 - Principal voltage-current characteristics of SCR's and triacs.

Operation of an SCR under reverse-blocking voltage is similar to that of a reverse-biased silicon rectifier or other semiconductor diodes. In this operating mode, the SCR exhibits a very high internal impedance, and a small reverse current flows through the p-n-p-n structure until the reverse breakdown voltage is reached, at which time the reverse current increases rapidly. For forward (positive) operation, the SCR is electrically bistable and exhibits either high impedance (forward-blocking or OFF state) or low impedance (forward-conducting or ON state). In the forward-blocking state, a small leakage current, considered to be of approximately the same value as that for reverse leakage, flows through the p-n-p-n structure. As the forward voltage is increased, a "breakdown" point is reached at which the forward current increases rapidly and the voltage across the SCR decreases abruptly to a very low voltage, referred to as the forward ON voltage. When the SCR is in the ON state, the forward current is limited primarily by the impedance of the external circuit. Increases in forward (principal) current are accompanied by only a slight change in ON-state voltage.

If the triac is considered as two parallel SCR's oriented in opposite directions to provide symmetrical current flow, the behavior of a triac under positive or reverse voltage operation is essentially the same as that of an SCR in the forward-blocking mode.

Gate Characteristics

The breakover voltage of a thyristor can be varied, or controlled, by injection of a signal at the gate terminal. Fig. 5

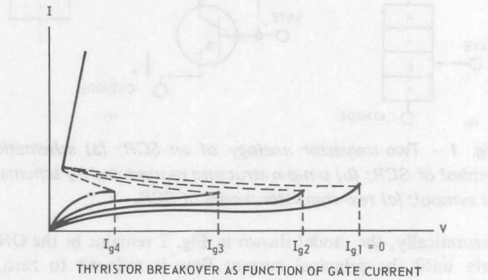


Fig.5 - Thyristor breakover as a function of gate current.

shows curves of breakover as a function of gate current for first-quadrant operation of an SCR. A similar set of curves can be drawn for both the first and the third quadrant to represent triac operation.

When the gate current I_g is zero, the applied voltage must reach the breakover voltage of the SCR or triac before switching occurs. As the value of gate current is increased, however, the ability of a thyristor to support applied voltage is reduced and there is a certain value of gate current at which the behavior of the thyristor closely resembles that of a rectifier. Because thyristor turn-on, as a result of exceeding the breakover voltage, can produce instantaneous power dissipation during the switching transition, an irreversible condition may exist unless the magnitude and rate of rise of principal current is restricted to tolerable levels. For normal operation, therefore, thyristors are operated at applied voltages lower than the breakover voltage, and are made to switch to the ON state by gate signals of sufficient amplitude to assure complete turn-on independent of the applied voltage. Once the thyristor is triggered to the ON state, the principal-current flow is independent of gate voltage or gate current, and the device remains in the ON state until the principal-current flow is reduced to a value below the holding current required to sustain regeneration.

The gate voltage and current required to switch a thyristor from its high-impedance (OFF) state to its low-impedance (ON) state at maximum rated forward anode current can be

determined from the circuit shown in Fig. 6. Resistor R_2 is selected so that the anode current specified in the manufacturer's ratings flows when the device latches into its low-impedance or ON state. The value of R_1 is gradually decreased until the device under test is switched from its OFF state to its low-impedance or ON state. The values of gate current and gate voltage immediately prior to switching are the values required to trigger the thyristor. For an SCR, there is only one mode of gate firing capable of switching the device into the ON state, i.e., a positive gate signal for a positive anode voltage. If the gate polarity is reversed (negative voltage), the reverse current flow is limited by the value of R_2 and the gate-cathode internal shunt. The value of power dissipated for the reverse gate polarity is restricted to the maximum power-dissipation limit imposed by the manufacturer.

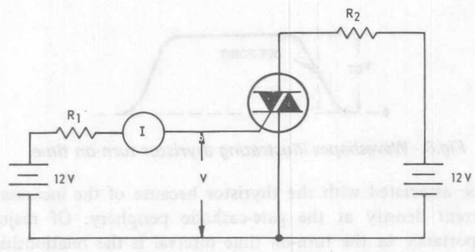


Fig.6 - Circuit used to measure thyristor gate voltage and current switching threshold.

Because of its complex structure, a triac can be triggered by either a positive or a negative gate signal regardless of the voltage polarity across the main terminals of the device. Fig. 7 illustrates the triggering mechanism and current flow within a triac. The gate trigger polarity is always referenced

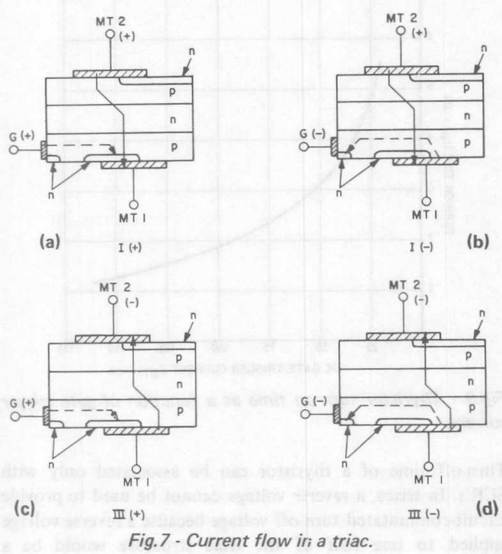


Fig.7 Current flow in a triac.

to main terminal 1. The potential difference between the two terminals is such that gate current flows in the direction indicated by the dotted arrow. The polarity symbol at main terminal 2 is also referenced to main terminal 1. The semiconductor materials between the various junctions within the pellet are labeled "p" and "n" to indicate the type of majority-carrier concentrations within the material.

For the various operating modes, the polarity of the voltage on main terminal 2 with respect to main terminal 1 is given by the quadrant in which the triac operates (either I or III), and the polarity of the gate signal used to trigger the device is given by the proper symbol next to the operating quadrant. For the I(+) operating mode, main terminal 2 and the gate are both positive with respect to main terminal 1. Initial gate current flows into the gate terminal, through the p-type layer, across the junction into the n-type layer, and out main terminal 1, as shown by the dotted arrow. As gate current flows, current multiplication occurs and the regenerative action within the pellet switches the triac to its ON state. Because of the polarities indicated between the main terminals, the principal current flows through the p-n-p-n structure as shown by the solid arrow. Similarly, for the other three operating modes, the initial gate-current flow is shown by the dotted arrow, and principal-current flow through the main terminals is shown by the solid arrow.

Because the direction of principal current influences the gate trigger current, the magnitude of the current required to trigger the triac differs for each mode. The operating modes in which the principal current is in the same direction as the gate current require less gate trigger current; modes in which the principal current is in opposition to the gate current require more gate trigger current.

Because triacs are bidirectional, they can provide full-cycle (360-degree) control of ac power from either a positive or a negative gate-drive signal. This feature is an advantage when it is necessary to control ac power from low-level logic systems such as integrated-circuit logic. With gate-power requirements for turn-on in the milliwatt region, triacs are capable of controlling power levels up to 10 kilowatts. Thus, the power gain associated with these thyristors far exceeds that of transistor counterparts in the semiconductor switching field.

Like many other semiconductor-device parameters, the magnitude of gate trigger current and voltage varies with the junction temperature. As thermal excitation of carriers within the semiconductor material increases, the increase in leakage current makes it easier for the device to be triggered by a gate signal. Therefore, the gate becomes more sensitive in all operating modes as the junction temperature increases. Conversely, if a triac or SCR is to be operated at low temperatures, sufficient gate trigger current must be provided to assure triggering of all devices at the lowest operating temperature expected in any particular application. Variations of gate-trigger requirements are given in the published data for individual thyristors.

The gate current specified in published data for thyristors is the dc gate trigger current required to switch an SCR or triac into its low-impedance state. For practical purposes, this dc value can be considered equivalent to a pulse current that has a minimum pulse width of 50 microseconds. For gate-current pulse widths smaller than 50 microseconds, the pulse-current curves associated with a particular device should be used to assure turn-on.

When pulse triggering of a thyristor is required, it is always advantageous to provide a gate-current pulse that has a magnitude exceeding the dc value required to trigger the device. The use of large trigger currents reduces variations in turn-on time, increases di/dt capability, minimizes the effect of temperature variation on triggering characteristic, and makes possible very short switching times. When a thyristor is initially triggered into conduction, the current is confined to a small area which is usually the more sensitive part of the cathode. If the anode current magnitude is great, the localized instantaneous power dissipation may result in irreversible damage unless the rate of rise of principal current is restricted to tolerable levels to allow time for current spreading over a larger area. When a much larger gate signal is applied, a greater part of the cathode is turned on initially; as a result, turn-on time is reduced, and the thyristor can support a much larger peak anode inrush current.

Switching Characteristics

Ratings of thyristors are based upon the amount of heat generated within the device pellet and the ability of the device package to transfer the internal heat to the external case. For high-performance applications in which switching of high peak current values but narrow pulse widths is desired, the internal energy dissipated during the turn-on process must be determined to assure that power dissipation is within ratings.

When thyristors (either triacs or SCR's) are triggered by a gate signal, the turn-on time consists of two stages, a delay time t_d and a rise time t_r, as shown in Fig. 8. The total turn-on time t_{gt} is defined as the time interval between the initiation of the gate signal and the time for the principal anode current flow through the thyristor to reach 90 per cent of its maximum value for a resistive load. The delay time t_d is defined as the time interval between the 50-per-cent point of the leading edge of the gate trigger voltage and the 10-per-cent point of the principal current for a resistive load. The rise time t_r is the time interval required for the principal current to rise from 10 to 90 per cent of its maximum value. The total turn-on time t_{on} is the sum of both delay and rise time ($t_d + t_r$).

Although the thyristor is affected to some extent by the peak off-state voltage and the peak on-state current level, the turn-on time is influenced primarily by the magnitude of the gate-trigger pulse current, as shown in Fig. 9. Faster turn-on time for larger gate drive is a result of a decrease in delay

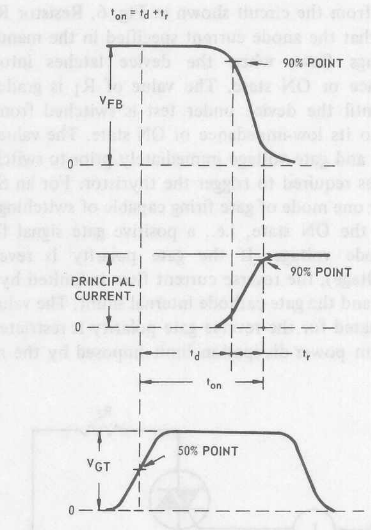


Fig.8 - Waveshapes illustrating thyristor turn-on time.

time associated with the thyristor because of the increased current density at the gate-cathode periphery. Of major importance in the turn-on time interval is the relationship between thyristor voltage and principal current flow through the thyristor. During the turn-on interval, the dynamic voltage drop is high and the current density can produce localized hot spots in the pellet area. Therefore, it is important that power dissipation during turn-on be restricted to levels within device specifications.

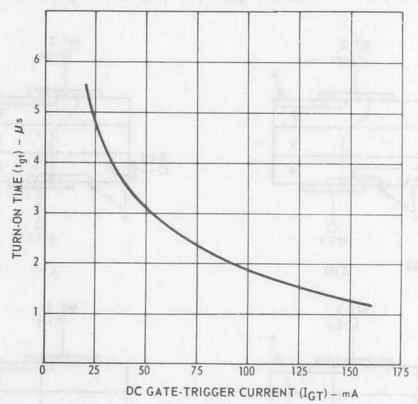


Fig.9 - Thyristor turn-on time as a function of gate trigger current.

Turn-off time of a thyristor can be associated only with SCR's. In triacs, a reverse voltage cannot be used to provide circuit-commutated turn-off voltage because a reverse voltage applied to one half of the triac structure would be a

forward-bias voltage to the other half. For turn-off times in an SCR, the recovery period consists of two stages, a reverse recovery time and a gate recovery time, as shown in Fig. 10.

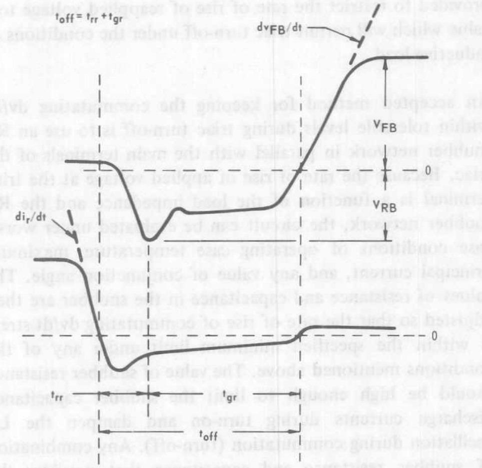


Fig. 10 - Waveshapes illustrating thyristor turn-off time.

When the forward current of an SCR is reduced to zero at the end of a conduction period, application of reverse voltage between the anode and cathode terminals causes reverse current to flow in the SCR until the time that the reverse current passes its peak value to a steady-state level called the reverse recovery time t_{rr}. A second recovery period, called the gate recovery time, t_{gr}, must then elapse for the forward-blocking junction to establish a depletion region so that forward-blocking voltage can be reapplied and successfully blocked by the SCR. The gate recovery time of an SCR is usually much longer than the reverse recovery time. The total time from the instant reverse recovery current begins to flow to the start of the forward- blocking voltage is referred to as circuit-commutated turn-off time t_q.

Turn-off time depends upon a number of circuit parameters, including on-state current prior to turn-off, rate of change of current during the forward-to-reverse transition, reverse-blocking voltage, rate of change of reapplied forward voltage, gate trigger level, the gate bias, and junction temperature. Junction temperature and on-state current have a more significant effect on turn-off than any of the other factors. With turn-off time specified on the manufacturer's data sheet and dependent upon the conditions as outlined above, turn-off time specification is only meaningful if all of the above critical parameters are available in the actual application.

For applications in which an SCR is used to control 60-Hz ac power, the entire negative half of the sine wave is a turn-off condition and more than adequate for complete turn-off. For applications in which the SCR is used to control the output of a full-wave rectifier bridge, however, there is no reverse voltage available for turn-off, and complete turn-off can be accomplished only if the bridge output is reduced to zero volts or the principal current is reduced to a value lower than the device holding current.

Because turn-off times are not associated with triacs due to the physical structure of the device, a new term is introduced called "critical rate of rise of commutation voltage", or the ability of a triac to commutate a fixed value of current under specified conditions. The rating can be explained by consideration of two SCR's in an inverse parallel mode, as shown in Fig. 11. SCR-1 is assumed to be in the conducting state

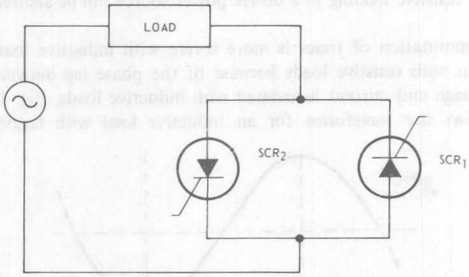


Fig. 11 - Circuit used to demonstrate critical rate of rise of commutation voltage.

with forward current established. As the principal cur.ent flow crosses the zero reference point, a small reverse current flows in SCR-1 until the time that the SCR reverts to the OFF state. The principal current is then diverted to SCR-2, provided that sufficient gate current is available to that device.

The structure of a triac shown in Fig. 12 indicates that the main blocking junctions are common to both halves of the

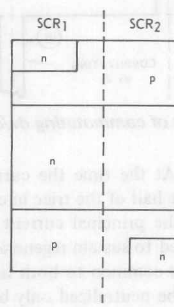


Fig. 12 - Structure of a triac.

device. When the first half of the triac structure (SCR-1) is in the conducting state, quantity of charge accumulates in the n-type region as a result of the principal current flow. As the principal current crosses the zero reference point, a small

reverse current is established as a result of the charge remaining in the n-type region. Because the n-type region is common to both halves of the devices, this reverse recovery current becomes a forward current to the second half of the triac. The current resulting from stored charge may cause the second half of the triac to go into the conducting state in the absence of a gate signal. Once current conduction has been established by application of a gate signal, therefore, complete loss in power control can occur as a result of interaction within the n-type base region of the triac unless sufficient time elapses to assure turn-off. It is imperative that triac manufacturers provide sufficient information regarding commutating capability under maximum current and case-temperature conditions so that triac control of ac power for resistive loading in a 60-Hz power source can be assured.

Commutation of triacs is more severe with inductive loads than with resistive loads because of the phase lag between voltage and current associated with inductive loads. Fig. 13 shows the waveforms for an inductive load with lagging

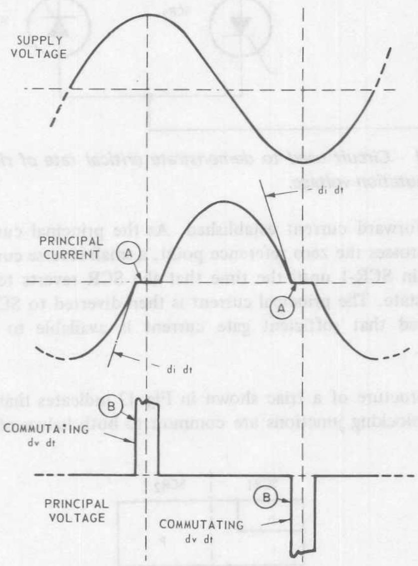


Fig.13 - Waveshapes of commutating dv/dt characteristics.

current power factor. At the time the current reaches zero crossover (point A), the half of the triac in conduction begins to commutate when the principal current falls below the holding current required to sustain regeneration. Because the high-voltage junction is common to both halves of the triac, the stored charge can be neutralized only by recombination. At the instant the conducting half of the triac turns off, an applied voltage opposite to the current polarity is applied across the triac terminals (point B). Because this voltage is a forward bias to the second half of the triac, the sudden reapplied voltage in conjunction with the remaining stored charge in the high-voltage junction reduces the over-all device capability to support a fast rate of rise of applied voltage. The result is a loss of power control to the load, and the device remains in the conducting state in absence of a gate signal. Therefore, it is imperative that some means be provided to restrict the rate of rise of reapplied voltage to a value which will permit triac turn-off under the conditions of inductive load.

An accepted method for keeping the commutating dv/dt within tolerable levels during triac turn-off is to use an RC snubber network in parallel with the main terminals of the triac. Because the rate of rise of applied voltage at the triac terminal is a function of the load impedance and the RC snubber network, the circuit can be evaluated under worst-case conditions of operating case temperature, maximum principal current, and any value of conjunction angle. The values of resistance and capacitance in the snubber are then adjusted so that the rate of rise of commutating dv/dt stress is within the specified minimum limit under any of the conditions mentioned above. The value of snubber resistance should be high enough to limit the snubber capacitance discharge currents during turn-on and dampen the LC oscillation during commutation (turn-off). Any combination of snubber resistance and capacitance that provides the requirements outlined above is considered satisfactory.

Some of the factors affecting commutating dv/dt capability of triacs are temperature, current magnitude, rate of change of current during commutation, and frequency of the applied principal current. With frequency directly related to commutating di/dt, early triac use was restricted to 60-Hz applications. Continued technological advances in triac device structure has resulted in faster "turn-off" capability and made possible a new family of triacs having 400-Hz commutating capability that is now being offered to circuit designers who must work with 400-Hz source voltages.

Another important parameter for thyristors is the "critical rate of rise of off-state voltage". A source voltage can be suddenly applied to an SCR or a triac which is in the OFF state through either closure of an ac line switch or transient voltages as a result of an ac line disturbance. If the fast rate of rise of the transient voltage exceeds the device rating, the thyristor may switch from the OFF state to the conducting state in the absence of a gate signal. If the thyristor is controlling alternating voltage, "false" turn-on (non-gated) resulting from a transient imposed voltage is limited to no more than half the applied voltage because turn-off occurs during the zero current crossing. However, if the source voltage suddenly applied to the OFF thyristor is a dc voltage, the device may switch to the ON state and turn-off could then be achieved only by circuit interruptions. The switching from the OFF state is caused by the internal capacitance of the thyristor. A steep-rising voltage dv/dt impressed across the terminals of a thyristor causes a capacitance-charging current to flow through the device. This charging current (i=Cdv/dt) is a function of the rate of rise of applied off-state voltage. If the rate of rise of voltage exceeds a critical value,

the capacitance-charging current exceeds the gate trigger current and causes device turn-on. Operation at elevated junction temperatures reduces the thyristor ability to support a steep rising voltage dv/dt because less gate current is required for turn-on. The effect of temperature on the critical rate of rise of off-state voltage is shown in Fig. 14.

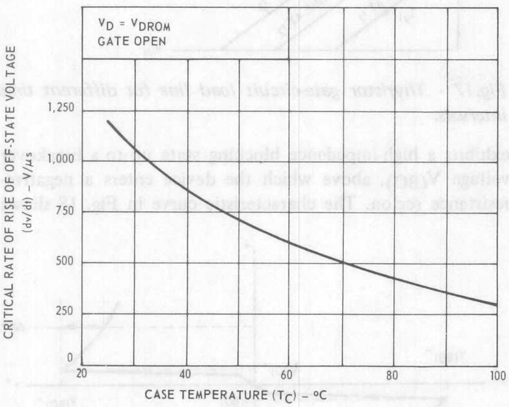


Fig. 14 - Critical rate of rise of off-state voltage as a function of case temperature.

Voltage transients which occur in electrical systems as a result of disturbance on the ac line caused by various sources such as energizing transformers, load switching, solenoid closure, contactors, and the like may generate voltages which are above the ratings of thyristors and result in spike voltages exceeding the critical rate of rise of off-state voltage capability. Thyristors, in general, switch from the OFF state to the ON state whenever the breakover voltage of the device is exceeded, and energy is then transferred to the load. Good practice in the use of thyristors exposed to a heavy transient environment is to provide some form of transient suppression.

For applications in which low-energy, long-duration transients may be encountered, it is advisable to use thyristors that have voltage ratings greater than the highest voltage transient expected in the system to provide protection against destructive transients. The use of voltage clipping cells is also effective. In either case, analysis of the circuit application will reveal the extent to which suppression should be employed. In an SCR application in which there is a possibility of exceeding the reverse-blocking voltage rating, it is advisable to add a clip cell or to use an SCR with a higher reverse-blocking voltage rating to minimize power dissipation in the reverse mode. Because triacs generally switch to a low conducting state, if the di/dt buildup of the principal current flow after turn-on is within device ratings it is safe to assume that reliable operation will be achieved under the specified conditions.

The use of an RC snubber is most effective in reducing the effects of the high-energy short-duration transients more frequently encountered in thyristor applications. When an RC snubber is added at the thyristor terminals, the rate of rise of voltage at the terminals is a function of the load impedance and the RC values used in the network. In some applications, "false" (non-gated) turn-on for even a portion of the applied voltage cannot be tolerated, and circuit response to voltage transients must be determined. An effective means of generating fast-rising transients and observing the circuit response to such transients is shown in Fig. 15. This circuit makes use of the "splash" effects of a mercury-wetted relay to transfer a capacitor charge to the input terminals of a control circuit. This approach permits generation of a transient of known magnitude whose rate of rise of voltage can easily be displayed on an oscilloscope. For a given load condition, the values in the RC snubber network can be adjusted so that the transient voltage at the device terminals is suppressed to a tolerable level. This approach affords the circuit designer with meaningful information as to how a control circuit will respond in a heavy transient environment. The circuit is capable of generating transient

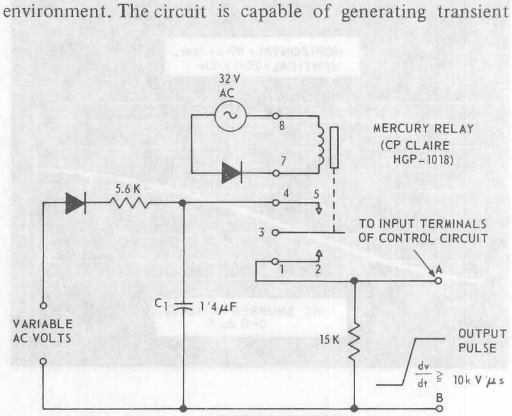


Fig. 15 - Circuit used to generate-fast rising transients.

voltages in excess of 10 kilovolts per microsecond, which exceeds industrial generated transients. The response of a 100-millihenry solenoid control circuit exposed to a fast-rising transient is shown in Fig. 16.

Use of Diacs For Control Triggering

Basically, thryristors are current-dependent devices, and the magnitude of gate current I_{GT} and voltage V_{GT} required to trigger a thyristor into the on-state varies. The point at which thyristor triggering occurs depends not only on the required gate current and voltage, but also on the trigger source impedance and voltage. Fig. 17 shows a family of curves representing the gate-circuit load line between the open-circuit source voltage and the short-circuit current for different time intervals. In a circuit which applies time-dependent variable voltage Vac to a load and the gate trigger current required to trigger the thyristor is derived from the same source Vac, devices that have a gate current I_{gl} are

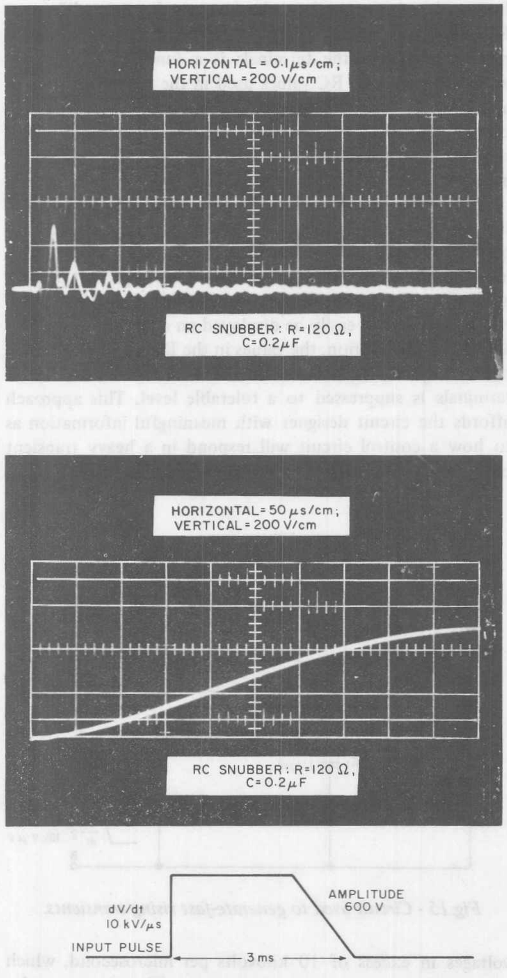


Fig.16 - Waveforms showing response of a 100-millihenry solenoid control circuit to a fast-rising transient.

triggered earlier in the ac cycle than devices that have a higher gate trigger current Fig. 3. Although the circuit is capable of providing variable power to the load, it is heavily dependent on the gate current distribution, and results in uncontrolled conduction angles for a given value of gate series resistance. Furthermore, the circuit does not provide the recommended gate-current overdrive for switching of the fast-rising high-amplitude load currents present in resistive loading. A more efficient circuit for control of variable power to a load that eliminates the need for tight gate-current distribution uses a solid-state trigger device, called a diac, which is voltage dependent.

The diac, often referred to as a bidirectional trigger diode, is a two-terminal, three-layer, transistor-like structure that

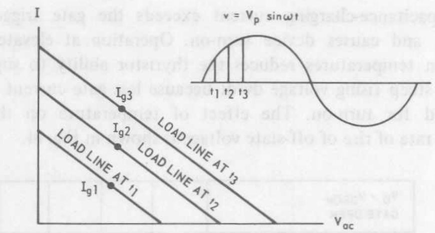


Fig.17 - Thyristor gate-circuit load line for different time intervals.

exhibits a high-impedance blocking state up to a breakover voltage $V_{(BO)}$, above which the device enters a negative-resistance region. The characteristic curve in Fig. 18 shows

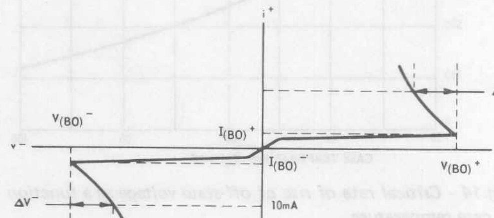


Fig.18 - Diac voltage-current characteristic.

the negative characteristics associated with diacs when they are exposed to voltages in excess of the breakover voltage $V_{(BO)}$. Because of their bidirectional properties and breakover voltage level, diacs are useful in triac control circuits in which variable power is to be supplied to a load. Because of their negative characteristic slope, diacs can also be used with capacitors to provide the fast-rising high-magnitude trigger current pulses recommended in thyristor applications which require efficient gate turn-on for the purpose of switching high-level load currents.

In normal applications, diacs are used in conjunction with RC phase networks to trigger triacs, as shown in Fig. 19. The

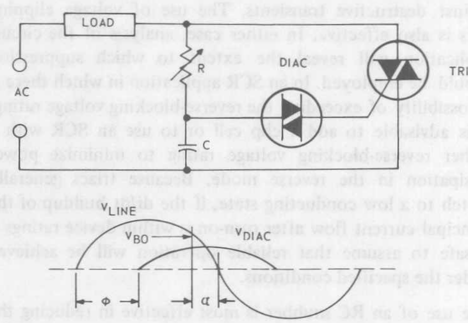


Fig.19 - Use of diac with RC phase network to trigger triac.

RC phase network provides an initial phase-angle displacement ϕ so that conduction angles in excess of 90 degrees can be realized. As the voltage on the capacitor begins to build up in a sinusoidal manner, the breakover voltage $V_{(BO)}$ of the diac is reached, the triac is turned on, and a portion of the ac input voltage is provided to the load, as represented by the angle α. As previously mentioned, the diac offers a negative-resistance region and is capable of providing current pulses whose magnitude and pulse width are a function of the capacitor C and the combined impedance of the diac and the gate and main terminal of the triac. When the voltage on the capacitor C reaches the breakover voltage $V_{(BO)}$, the capacitor does not discharge completely, but is restricted to some finite level as a result of the diac negative-impedance characteristic at high values of pulse current. Fig. 20 shows the peak pulse current of a diac as a function of the capacitances of the phasing capacitor C.

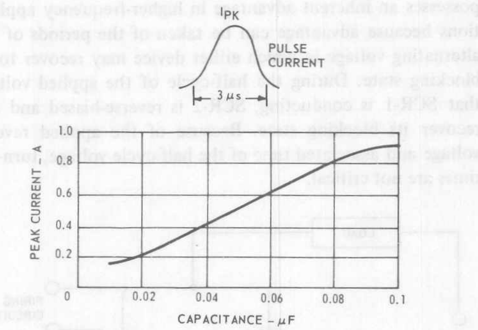


Fig.20 - Peak pulse current of a diac as a function of phasing capacitance.

Power Control Using Thyristors

In the control of ac power by means of semiconductor devices, emphasis has been placed on circuit simplicity, low cost, and small over-all package size. Thyristors meet these goals, and are also capable of providing either fixed or adjustable power to the load. Fixed power is achieved by use of the thyristor as an ON-OFF switch, and adjustable power through the use of an RC phase network which provides variable phase-gating operation. The following section discusses both SCR and triac circuit operations, and analysis of SCR and triac behavior for various circuit conditions.

Many fractional-horsepower motors are series-wound "universal" motors capable of operation from either an ac or a dc source. In the early stages of thyristor control, SCR's found wide acceptance in the control of universal motors, particularly in the portable power tools market. SCR's are capable of providing speed control over half of an ac sine wave, and, if full power is required, a simple shorting switch across the SCR provides the necessary function; such a switch is shown in Fig. 21. Turn-off parameters for this

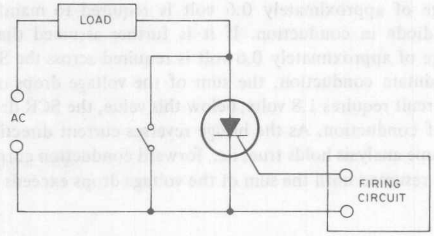


Fig.21 - Simple SCR half-wave control circuit.

circuit are not critical because the SCR has a half-cycle of applied negative voltage in which to recover. The SCR provides a reliable, highly efficient, long-life control for half-wave control circuits.

Fig. 22 shows a full-wave bridge that feeds a resistive load and uses an SCR as the control element for load current. Power control is accomplished by SCR turn-on at various conduction angles with respect to the applied voltage. The criteria for turn-off in this circuit is important because the SCR must recover its forward-blocking state during the time that the forward current stops flowing. Although this time interval may appear to be very small, close analysis of the voltage wave during the transition time in which the full-wave bridge reverses direction reveals that substantial time exists for turn-off.

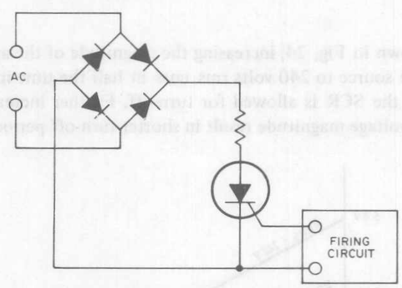


Fig.22 - Full-wave SCR bridge circuit.

Fig. 23 shows one-half of the bridge during the time that the forward current is approaching zero current. Two diodes are in series with the SCR; it is generally accepted that a diode

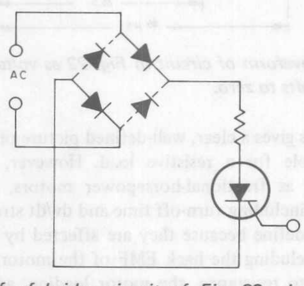


Fig.23 - Half of bridge circuit of Fig. 22 when forward current approaches zero for a resistive load.

voltage of approximately 0.6 volt is required to maintain each diode in conduction. If it is further assumed that a voltage of approximately 0.6 volt is required across the SCR to maintain conduction, the sum of the voltage drops over the circuit requires 1.8 volts; below this value, the SCR drops out of conduction. As the bridge reverses current direction, the same analysis holds true, i.e., forward conduction current is not resumed until the sum of the voltage drops exceeds 1.8 volts.

The waveform during the interval that the voltage wave goes from 1.8 volts to zero can be analyzed by reference to Fig. 24. A half-cycle (180 degrees) of conduction requires 8.3 milliseconds, one degree being equal to approximately 46 microseconds. Because a sine wave is linear for very small angles, a graph can be constructed to show the time interval during which the voltage is less than 1.8 volts for various magnitudes of applied voltage. Analysis of the voltage wave for an angle of one degree shows that an input voltage of 120 volts rms results in a voltage equal to 2.9 volts, which decays to zero in 46 microseconds. Because the SCR is non-conducting below a circuit threshold of 1.8 volts, a time of 28.5 microseconds then elapses while the voltage decays from 1.8 volts to zero. An equal time is required for the bridge to build up to the threshold voltage of 1.8 volts. Therefore, a total exposure time of 57 microseconds elapses in which the SCR is allowed to regain its forward-blocking state.

As shown in Fig. 24, increasing the magnitude of the applied voltage source to 240 volts rms cuts in half the time interval which the SCR is allowed for turn-off. Further increases in input voltage magnitude result in shorter turn-off periods.

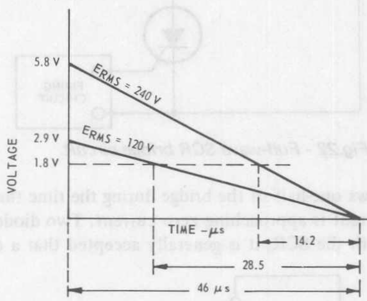


Fig.24 - Waveform of circuit in Fig. 22 as voltage wave goes from 1.8 volts to zero.

This analysis gives a clear, well-defined picture of the turn-off time available for a resistive load. However, for reactive loads, such as fractional-horsepower motors, the turn-off conditions, including turn-off time and dv/dt stress, are more difficult to define because they are affected by a number of variables, including the back EMF of the motor, the ratio of inductance to resistance, the motor loading, and the phase angle of motor current to source voltage. Normally, turn-off times for SCR's are industry-standardized to include peak forward current, rate of rise of reverse current, peak forward blocking voltage applied, and rate of rise of applied blocking voltage. The presence of the applied reverse current helps to shorten turn-off times because the reverse current sweeps out the charge in the blocking junction. For SCR operation from a full-wave bridge in which there is no appreciable reverse voltage available, turn-off is accomplished through recombination, and the effects of circuit loading on SCR operation must be clearly evaluated.

Full-wave ac switching can also be performed by use of two SCR's in an inverse parallel mode, often referred to as a "back-to-back" SCR pair, as shown in Fig. 25. This circuit can be used as a simple static switch or as a variable phase control circuit. It does not make use of a full-wave diode bridge, but simply uses the SCR's in an alternating mode. The circuit has the disadvantage of separate trigger logic, but possesses an inherent advantage in higher-frequency applications because advantage can be taken of the periods of the alternating voltage in which either device may recover to its blocking state. During the half-cycle of the applied voltage that SCR-1 is conducting, SCR-2 is reverse-biased and can recover its blocking state. Because of the applied reverse voltage and associated time of the half-cycle voltage, turn-off times are not critical.

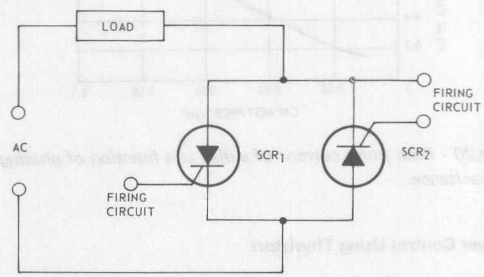


Fig.25 Full-wave ac switching circuits using a "back-to-back" SCR pair.

This two-SCR circuit is often favored over a triac circuit, even though separate trigger sources are required, because it is supposed to have better commutating capability. Fig. 26 shows the waveforms of commutating dv/dt for the SCR circuit. If the load is inductive with lagging current power factor, the conducting SCR commutates at the time the principal current reaches zero crossover (point A) and reverts to the blocking state; a reapplied voltage of opposite polarity equal to the source voltage then appears across the non-conducting SCR. Because this voltage is a forward-bias voltage to the non-conducting SCR, device turn-on can occur if the rate of rise of applied forward voltage exceeds the device rating for critical rate of rise of off-state voltage. For inductive loading in an inverse-parallel-mode SCR application, power control to the load can be lost if the rate of rise of applied voltage is exceeded.

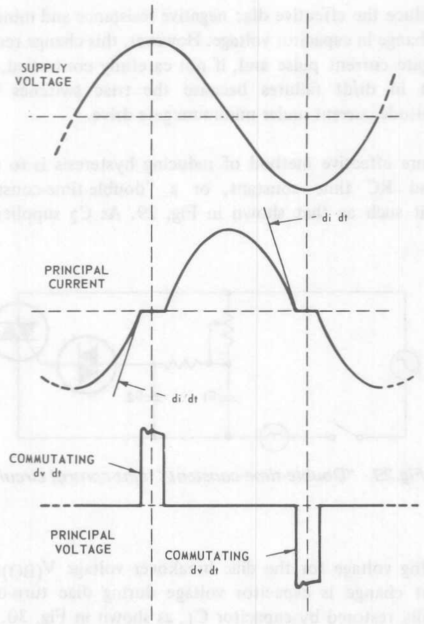


Fig.26 - Waveforms of commutating dv/dt for SCR circuit of Fig. 25.

Although it may appear that the rate of rise is extremely fast, closer circuit evaluation reveals that the dv/dt stress is restricted to some finite value which is a function of the load reactance L and the device capacitance C. Therefore, it is important that the rate of rise of applied voltage during commutation not exceed the device specification for critical rate of rise of off-state voltage under worst-case condition or unreliable operation may result. It is generally good practice in inverse-parallel operation to use an RC snubber network across the SCR pair to limit the rate of rise to some finite value below the minimum requirements, not only to limit the voltage rise during commutation, but also to suppress transient voltage that may occur as a result of ac line disturbances.

As previously mentioned, the use of semiconductor devices for ac power control has emphasized circuit simplicity, low cost, and small over-all package size. The development of the bidirectional triode thyristor, referred to as a triac, achieved all of these goals. Triacs can perform the same functions as two SCR's for full-wave operation, and also simplify gate logic requirements for triggering.

A simple, inexpensive triac circuit that can provide variable power to a load over a full cycle of applied voltage is the light-dimmer circuit. This circuit contains a diac, a triac, and an RC phase-control network. The basic light-dimmer circuit is described below because it provides a good example of triac behavior as related to load requirements and of the operation of a diac in an RC phase-control circuit.

Fig. 27 shows the basic triac-diac light-dimmer control circuit with the triac connected in series with the load. During the beginning of each half-cycle, the triac is in the off-state and the entire line voltage is across the triac; therefore, no voltage appears across the load. (Actually, there is some voltage across the load as a result of triac leakage currents, which are a function of applied voltage and junction temperature. However, these leakage currents are relatively small, at most in the milliampere range, and the resulting load voltages are generally ignored.)

The RC charge-control circuit is in parallel with the control triac, and the applied voltage serves to charge the timing capacitor C through the variable resistor R. When the voltage across C reaches the breakover voltage $V_{(BO)}$ of the diac, the capacitor discharges through the diac and the gate-to-main-terminal-1 impedance of the triac and turns on the control triac. At this point, the line voltage is transferred to the load for the remainder of the applied half-cycle voltage. As the load current reverses direction (zero crossing), the triac turns off and reverts to the blocking state. This sequence of events is repeated for every following half-cycle of applied voltage.

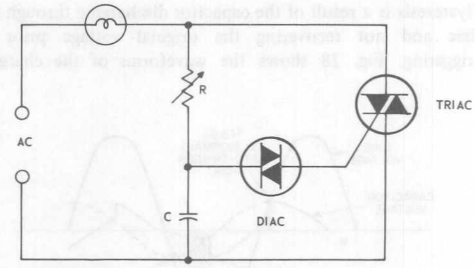


Fig.27 - Basic triac-diac light-dimmer control circuit.

If the value of resistance R is decreased, the capacitor charges to the breakover voltage $V_{(BO)}$ of the diac earlier in the ac cycle; the power supplied to the load is then increased and the lamp intensity is effectively increased. If the value of resistance R is increased, triac triggering occurs later in the ac cycle and applied voltage to the load is reduced; the result is decreased lamp intensity. Therefore, changes in the resistance value R effectively apply variable power to a load (which is a lamp load in the circuit of Fig. 27, but could also be a motor load or heating element).

Although the load is arbitrarily placed in series with main terminal 2, the circuit performs equally as well if the load is shifted to main terminal 1. (Actually, any commercial lamp dimmer available has two wires brought out for external connection, and the chance that the load will be connected to main terminal 1 is 50 per cent.) The only requirements for reliable operation are that the RC phase network be in parallel with the triac and that capacitor-discharge loop currents be directed from the diac to the triac gate and main terminal 1. Although the basic light-control circuit operates

with the component arrangement shown in Fig. 27, additional components are often added to reduce hysteresis effects, extend the effective range of power control, and suppress radio-frequency interference.

Hysteresis in triac phase-control circuits is referred to as the ratio of applied load voltage when the triac initially turns on (as control potentiometer is slowly reduced from some high value) to the value of load voltage prior to "extinguishing" (as the control potentiometer is slowly increased to some higher value). If the circuit has high hysteresis, the control potentiometer travel may be as high as 25 per cent before triac turn-on occurs, after which the control potentiometer may be turned back 15 per cent before the triac "extinguishes". Hysteresis is an undesirable feature if the circuit application requires low-level lamp illumination because a momemtary drop in line voltage may result in the triac "extinguishing" or missing one half-cycle of applied voltage when the capacitor voltage is barely equal to the breakover voltage $V_{(BO)}$ of the diac. If this condition exists, the control potentiometer must be reduced to "start up" the triac again.

Hysteresis is a result of the capacitor discharging through the diac and not recovering the original voltage prior to triggering. Fig. 28 shows the waveforms of the charging

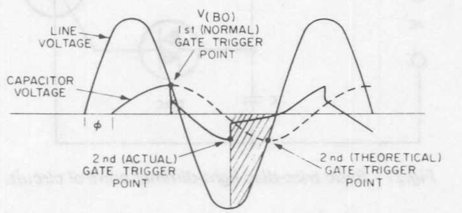


Fig.28 - Charging cycle of capacitor-diac network in Fig. 27 (high hysteresis).

capacitor C as related to the applied line voltage. The initial displacement angle ϕ is a result of the phase angle due to the value of the RC components used. As the value of the control potentiometer is slowly reduced, the value of charging voltage reaches the breakover voltage $V_{(BO)}$ of the diac, and the triac allows that portion of the ac wave remaining to appear at the load, as represented by the shaded area at the first trigger point. At this point, there is an abrupt change in capacitor voltage (Δ V). Therefore, as the capacitor charge reverses direction, the second trigger point is reached much earlier in the next half-cycle, and that portion of the ac wave remaining appears across the load, as represented by the shaded area at the second trigger point. The second trigger point and subsequent trigger points represent the steady-state level at which triggering occurs. Some reduction in hysteresis can be realized by inserting a resistor in series with the diac to reduce the effective diac negative resistance and minimize the change in capacitor voltage. However, this change reduces the gate current pulse and, if not carefully controlled, may result in di/dt failures because the triac switches high-magnitude current under minimum gate drive.

A more effective method of reducing hysteresis is to use a second RC time constant, or a "double-time-constant" circuit such as that shown in Fig. 29. As C_2 supplies the

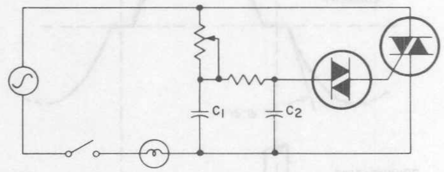


Fig.29 - "Double-time-constant" light-control circuit.

charging voltage for the diac breakover voltage $V_{(BO)}$, the abrupt change is capacitor voltage during diac turn-on is partially restored by capacitor C_1, as shown in Fig. 30. The restoring of the charge on C_2 maintains the original triggering point very closely and results in extended range of the control setting. This triac circuit can be turned on for very low levels of applied voltage and is not prone to "extinguishing" for line-voltage drops.

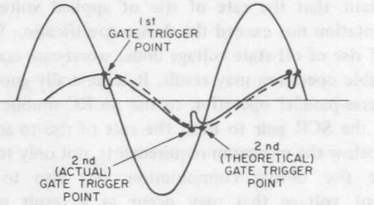


Fig.30 - Charging cycle of capacitor-diac network in Fig. 29 (reduced hysteresis).

Because triac switching from the high-impedance to the low-impedance state can occur in less than one microsecond, the current applied to the load increases from essentially zero to a magnitude limited by the load impedance within the triac switching time. This rapid rise of load current produces radio-frequency interference (RFI) extending into the range of several megahertz. Although this rapid rise does not affect television and FM radio frequencies, it does affect the short-wave and AM radio bands. The level of RFI generated is well below that caused by small ac/dc brush-type motors, but some means of RFI suppression is generally required if

the triac phase-control circuit is to be used for any extended period of time in an environment in which RFI generation cannot be tolerated.

A reasonably effective suppression technique is shown in Fig. 31. An inductor is connected in series with the triac control circuit to restrict the current rate of rise, and a filter capacitor is used in parallel with the entire network to bypass high-frequency signals.

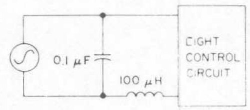


Fig.31 - RFI-suppression network.

The values shown in Fig. 31 are effective in reducing RFI noise for rms load currents up to 6 amperes to such an extent that the effects on short-wave and AM signals are either minimized or considered tolerable. For values above 6 amperes rms, additional suppression can be achieved by use of dual chokes in the ac lines to the triac network. Depending on the circuit performance required, such suppression may or may not be effective and other means of triac control may be required.

An alternate method of providing high-current heating controls is through use of a proportional control circuit using integral-cycle synchronous switching or zero-voltage switching. This approach varies the average power to the load through controlled bursts of full cycles of ac voltage to the load by turning on the triac at the beginning of the zero-voltage crossing. Because the triac turns on near zero current, the sudden current steps associated with phase-control circuits and the RFI generated are minimized. The RCA-CA3059 zero-voltage switch is a monolithic integrated circuit used primarily as a trigger-current generator for control of thyristor turn-on during the zero-voltage transition. This circuit has many features, one of which is a fail-safe circuit which inhibits output pulses in the event that the external sensor is opened or shorted.

Conclusions

This Note has reviewed thyristors from the viewpoints of temperature and voltage conditions, gate trigger characteristics, and effects of SCR's and triacs on circuit performance. The availability of power thyristors gives design engineers greater freedom in achieving circuit simplicity, low cost, and small package assembly than electromechanical or tube counterparts. Technological improvements are far from reaching the saturation level, but are opening new doors for circuit application. The impact of thyristor applications is being felt in normal everyday environments such as residential lamp dimming, TV deflection systems, home appliances, marine ignition, automotive applications, electric heating, comfort controls, and igniters for fuel-fired furnaces. Industrial applications for multiple-horsepower motors, lamp display boards, inverters, relay protection or replacement, radar, sonar, and emergency standby generating systems are now finding widespread acceptance in thyristor controls. The introduction of RCA triacs fully characterized for 400-Hz commutating capability opens the doors to many aircraft support applications which previously were devoid of the advantages offered in solid-state design. It appears that the answer to most power-control applications may be the thyristor.

Thyristor Control of Incandescent Traffic-Signal Lamps

by C.P. Knudsen

This Note discusses the use of thyristors in the control of traffic signals. The thyristor most applicable to this application is the triac, which can carry the electrical power required for incandescent traffic-light bulbs, yet can be gated by the low-power signals from electronic control timers or monitoring computers. In addition, the triac is able to handle the large transient currents that result from cold filament turn-on (inrush) and filament rupture (flashover). Triac operation, stresses on triacs in operation with incandescent lamps, and a number of triac circuits for control of incandescent lamps in traffic signal applications are discussed below.

TRIAC OPERATION

A triac, shown schematically in Fig. 1(a), is a bidirectional triode thyristor. In the absence of a gate signal, the triac blocks both portions of an ac sine wave, but a steady-state or pulsed gate signal will switch it on as in Fig. 1(b). The gate signal can be either positive or negative with respect to main terminal no. 1 (MT1), while MT2 can also be either positive or negative referenced to MT1; the four possible modes of switching are depicted in Table I. For example, when a triac is triggered by connecting a resistor between MT2 and the gate, as shown in Fig. 2, the triac operates in the I+ and III− modes in energizing the ac load. Other thyristor characteristics will be introduced below as needed, while an extensive review of thyristors is available in RCA Application Note AN-4242, "A Review of Thyristor Characteristics and Applications".

SURGE CURRENT THROUGH TRIACS IN INCANDESCENT-BULB OPERATION

The traffic-control circuit designer must be aware of two characteristics of incandescent bulbs: end-of-life filament rupture and cold-filament inrush surge. Both these transient conditions impose a high surge stress on the controlling triac, which without proper circuit design can be destructive.

Flashover

Flashover is a short-duration, extremely high-current surge through the triac that is initiated when a lamp filament ruptures. The rupture is most likely to occur as a result of a termination in bulb life; however it can be caused by a mechanical shock. The mechanism of flashover is initiated by

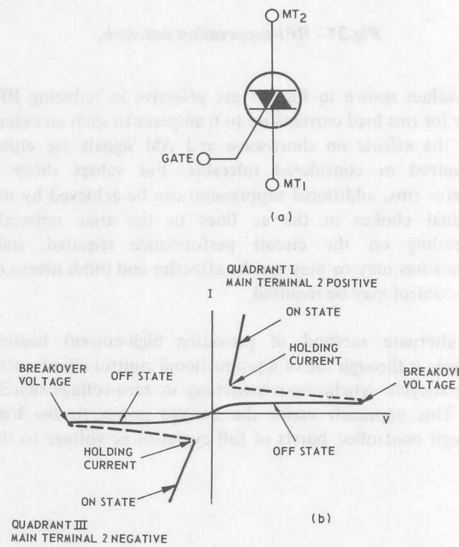


Fig. 1– (a) Schematic symbol, and (b) principal voltage-current characteristic for a triac.

Table I — Four Gate-Trigger Modes For Triac

MODE	MT2	G
I+	+	+
I−	+	−
III+	−	+
III−	−	−

Polarities are referenced to MT1.

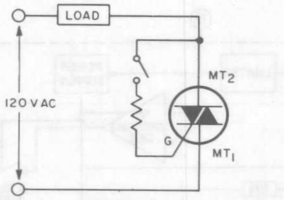


Fig. 2– Example of I+, III- gating of triac.

the gap formed when rupturing occurs. The instantaneous value of line voltage across the break sets up an electric field that ionizes the gases in close proximity to the gap. The ionized gases, usually argon and nitrogen, provide an electrical conduction path across the gap, and the resulting current heats and ionizes more gases until an arc is formed across the filament lead-in wires. The arc is maintained as long as the regenerative heating and ionization continue. Finally, because of either increasing arc length or decreasing ac line voltage, or both, the electric field becomes too weak to sustain the arc, and the arc is extinguished.

Fig. 3 shows a flashover current pulse. Its magnitude and duration depend on many factors. The actual peak magnitude of the source voltage, the voltage phase at the instant of filament rupture, and the impedance of the lead wires and other circuitry (including RFI filters) all affect the duration and magnitude of the surge. Typical values can be given for the stress of flashover at a load center point. For bulbs of less than 75 watts the duration of the surge can be typically less than 2 milliseconds. For bulbs of 100 to 150 watts the duration of the surge can be typically less than 4 milliseconds. The magnitude of surge can vary considerably, with typical peak values ranging from 80 to 200 amperes when the flashover occurs near the maximum voltage point. If the flashover occurs at a zero-voltage crossing, the current surge may be reduced as a result of the dependence of the magnitude on the voltage phase at rupture.

Because of the short duration of the flashover current, it is usually difficult to provide circuit fuse protection against flashover. Most incandescent bulbs are provided with a fuse built into one of the lead-in wires. This built-in fuse is not 100-per-cent effective against flashover and therefore cannot be depended upon to protect the triac. Fusing of triac circuits is described in more detail in the following discussion of inrush current.

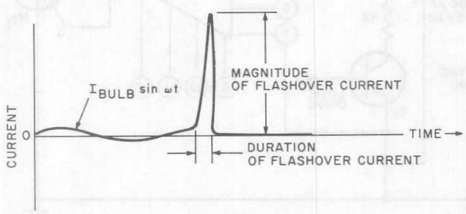


Fig. 3– Flashover current at peak voltage point.

Inrush

In tungsten-filament lamps, the cold filament resistance is approximately 1/18 to 1/12 of the hot filament resistance. The actual currents in a circuit under inrush and steady-state conditions do not vary in these ratios, however, because of the inductance and external limiting resistance of the circuitry, including the lead-in wires to the bulb. Furthermore, it is obvious that the highest inrush current will occur at the peak of the voltage sine wave in a lamp load circuit. If switching occurs at any other phase of the voltage sine wave, the peak current through the bulb is less than "worst case". Typically, the maximum inrush peak current can be ten times as great as the steady-state peak current, while the peak inrush current with zero-voltage switching can be approximately five times as great as the steady-state peak current, as shown in Fig. 4. Thus zero-voltage switching of a lamp effects a soft turn-on that reduces the initial peak of inrush current by half and greatly increases bulb life. This increase of bulb life by zero-voltage switching has been verified by test results; an increase in life of approximately ten times, with a 90 per cent confidence level, has been reported. Thus maintenance costs are reduced and system reliability increased.

Fig. 4 shows how the current in a lamp circuit decreases to the steady-state value. The rate of decrease depends upon the thermal time constant of the tunsten filament. A

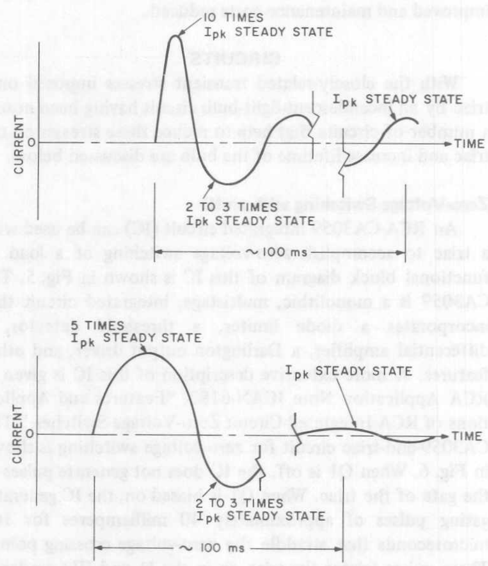


Fig. 4– (a) Inrush current at peak voltage point, and (b) inrush current at zero-voltage point.

a bulb is exposed to its most severe normal operating stress during inrush, the weakest spot of the filament often ruptures and causes a flashover at turn-on. Most often, switching and flashover occur at some point other than the peak voltage; therefore the resulting peak current is usually within the handling capability of the triac.

Fuses in incandescent-lamp circuits must not blow under the stress of inrush current, yet must blow under flashover current. For low-power bulbs the flashover current is substantially greater than the peak inrush current, and fuse protection is simple. For example, a 100-watt bulb might have a typical flashover current of 100 to 200 amperes and a typical inrush current of 10 amperes. For large-wattage bulbs, however, fusing is difficult. For a 1000-watt bulb, the peak flashover current might still be between 100 and 200 amperes, while the peak inrush current is approximately 120 amperes. Fuses set to blow at 150 amperes peak flashover current of short duration may also blow under the long-duration, slightly-lower-amplitude stress of inrush. As a result, a fusing solution to the problem of triac protection would be marginally reliable. One solution is to use a 40-ampere triac (available in the RCA-2N5443 series), which has a single-cycle surge capability of 300 amperes, to control this 10-ampere load. Here again system reliability would be improved and maintenance costs reduced.

CIRCUITS

With the closely-related transient stresses imposed on a triac by an incandescent-light-bulb circuit having been noted, a number of circuits that help to reduce these stresses on the triac and increase lifetime of the bulb are discussed below.

Zero-Voltage Switching with an IC

An RCA-CA3059 integrated circuit (IC) can be used with a triac to accomplish zero-voltage switching of a load. A functional block diagram of this IC is shown in Fig. 5. The CA3059 is a monolithic, multistage, integrated circuit that incorporates a diode limiter, a threshold detector, a differential amplifier, a Darlington output driver, and other features. A more extensive description of this IC is given in RCA Application Note ICAN-6182, "Features and Applications of RCA Integrated-Circuit Zero-Voltage Switches." The CA3059-and-triac circuit for zero-voltage switching is shown in Fig. 6. When Q1 is off, the IC does not generate pulses to the gate of the triac. When Q1 is biased on, the IC generates gating pulses of approximately 40 milliamperes for 100 microseconds that straddle the zero-voltage crossing points. These pulses trigger the triac on in the I+ and III+ modes at the zero-voltage crossing for the resistive-tungsten-filament bulb and effect the desired result of decreasing inrush current.

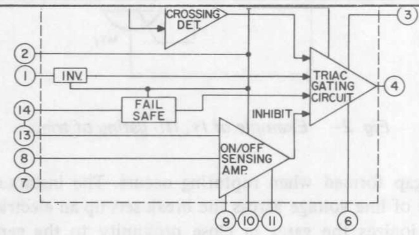


Fig. 5– Functional block diagram of the RCA-CA3059 integrated-circuit zero-voltage switch.

The circuit shown in Fig. 6 has one disadvantage for traffic controls, in which the bulb load is usually grounded and the power circuit ground and the logic ground are common. This arrangement presents a severe problem of interfacing between logic and power circuitry. If the load in Fig. 6 were grounded, terminal No. 4 of the CA3059 would be at line voltage above ground and the substrate (terminal No. 7) at ground potential when the bulb was energized. As a result, the IC would be destroyed. Similar problems are encountered whenever the logic circuitry is directly coupled with the triac power circuit and the load is grounded. However, this problem is eliminated in the discrete-component circuits described below.

Discrete-Component Zero-Voltage Switching

A discrete-component circuit that accomplishes zero-voltage switching of a grounded tungsten filament load is

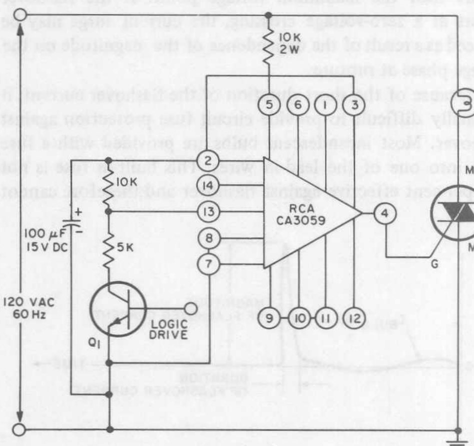


Fig. 6– Circuit that uses the CA3059 and a triac to switch a lamp at zero voltage.

shown in Fig. 7. With Q1 on, T1 is on and source voltage is shunted away from the load. With Q1 biased off, T1 is off and T2 is gated on through R1 and R3. When T2 conducts, it connects R4 from gate to MT2 of T3, and thus triggers T3 on in the I+ and III- modes. Because T2 is a sensitive-gate device, it turns on close to the zero-voltage point; therefore, the load is also zero-voltage switched after the initial turn-on. For a typical T2300B device, triggering in the I+ and III- modes results in firing at about 7 volts peak on the line. After T3 is turned on, the triggering circuitry is shorted; therefore, no triggering power is dissipated while the lamp is on.

Filament Pre-Heating

Another approach to reducing the inrush current is shown in Fig. 8, where a filament pre-heater function is included in the switching arrangement. In this circuit, when Q1 is off the logic interfacing triac T1 is off. R3, which can be a fixed resistor of approximately 98 kilohms, is set so that T2 is fired for only a small portion of the voltage cycle. This firing is accomplished by the standard double-time-constant lamp-dimmer gate circuitry of T2. The low-conduction-phase firing of the bulb keeps the tungsten filament warm but not hot enough to radiate any readily visible light. When Q1 is turned on, T1 is gated on and R3 is shorted, and the lamp load turns on.

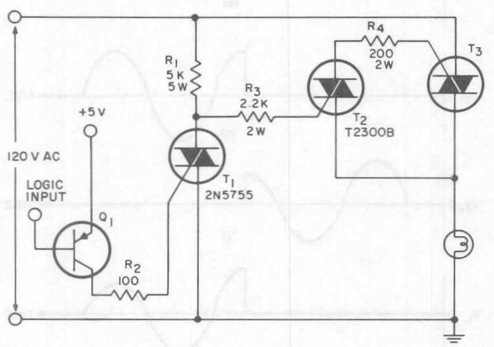


Fig. 7— Discrete-component circuit used to switch a grounded load at zero voltage.

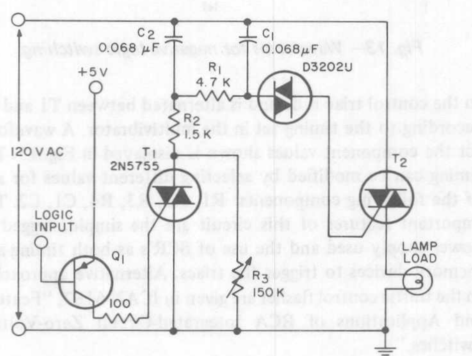


Fig. 8— A circuit including a filament pre-heat arrangement.

The associated waveforms are shown in Fig. 9. For a 200-watt bulb in the circuit of Fig. 8, the first peak of current through the bulb was 7.5 amperes when the warm up circuit was used and 25 amperes with cold-filament inrush.

These circuits of Figs. 7 and 8 show that triacs can be used to switch power lamp loads and also interface with low-level logic systems. They also show how some of the stresses involved with the switching of incandescent lamps can be reduced. Other switching circuitry for use in traffic controls is discussed below.

OTHER APPLICABLE ON-OFF SWITCHING CIRCUITS

Two other circuits that can be used in the traffic control area are shown in Figs. 10 and 12. These circuits have the advantages of a common ground between logic and power circuitry, grounded bulbs, and isolation between the dc logic and the power circuitry afforded by use of the interfacing logic triacs.

In the positive-logic switching circuit of Fig. 10, logic triac T1 is used to interface between the low level logic and the load triac T2. With T1 gated on, C1 is charged through R1 to the breakover voltage of the diac, at which point T2 and the load are triggered on. The various circuit waveforms are shown in Fig. 11. As Fig. 11(d) shows, there is continuous gate power driving T2 whenever T1 is on and thus the light is on hard.

A variation of this circuit with opposite (negative) logic is shown in Fig. 12. In this circuit, when T1 is triggered on, T2 and the lamp are off. When T1 is off, C1 can charge through R1 and R2 to diac breakover, which discharges C1 into the gate of T2 and energizes the load. The waveforms of this circuit are shown in Fig. 13. Little gate power is dissipated in this circuit because T2 shorts across its gate circuitry when it is on.

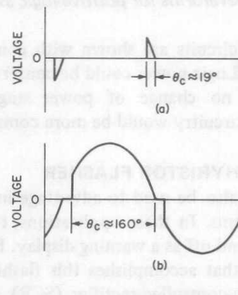


Fig. 9— Waveforms for circuit in Fig. 8: (a) voltage on bulb when Q1 is off; (b) voltage on bulb when Q1 is on.

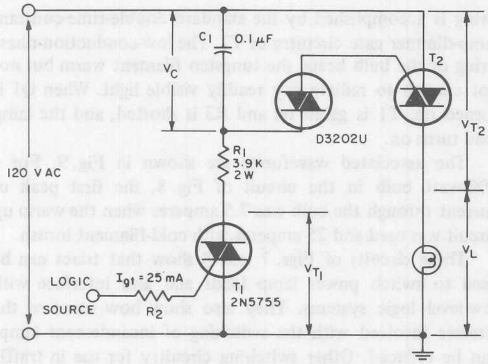


Fig. 10— Positive-logic bulb-switching circuit.

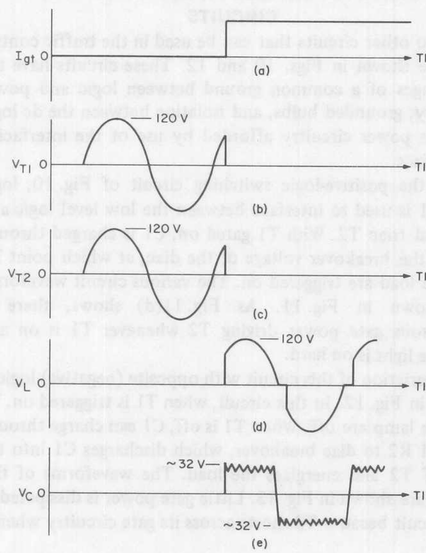


Fig. 11— Waveforms for positive-logic switching.

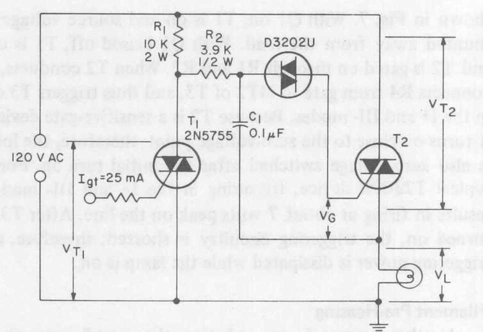


Fig. 12— Negative-logic bulb-switching circuit.

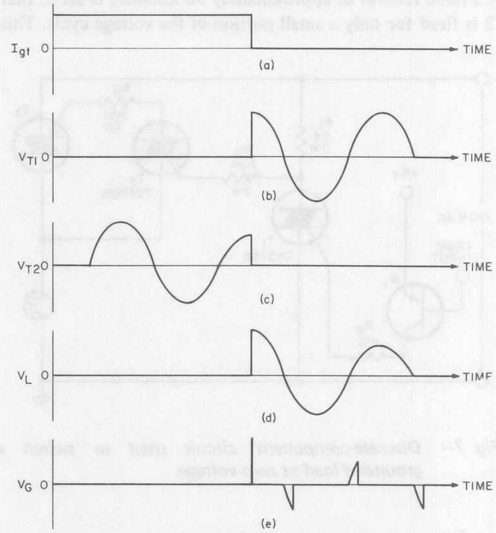


Fig. 13— Waveforms for negative-logic switching.

Both of these circuits are shown with continuous gate drive into triac T1. Logic power could be conserved by use of pulse drive, with no change of power stage operation; however, the logic circuitry would be more complex.

THYRISTOR FLASHER

Thyristors can also be used to advantage in flasher-type traffic-control systems. In these applications, two lights are usually flashed on and off as a warning display. Fig. 14 shows a thyristor circuit that accomplishes this flashing function. As shown, a silicon-controlled-rectifier (SCR) multivibrator functions as the timer and flasher-triggering driver. The drive to the control triac is dc and is alternated between T1 and T2 according to the timing set in the multivibrator. A waveform for the component values shown is displayed in Fig. 15. The timing can be modified by selecting different values for any of the following components: R1, R2, R3, R4, C1, C2. The important features of this circuit are the simple, rugged dc power supply used and the use of SCR's as both timing and memory devices to trigger the triacs. Alternative approaches to the traffic control flasher are given in ICAN-6182, "Features and Applications of RCA Integrated-Circuit Zero-Voltage Switches."

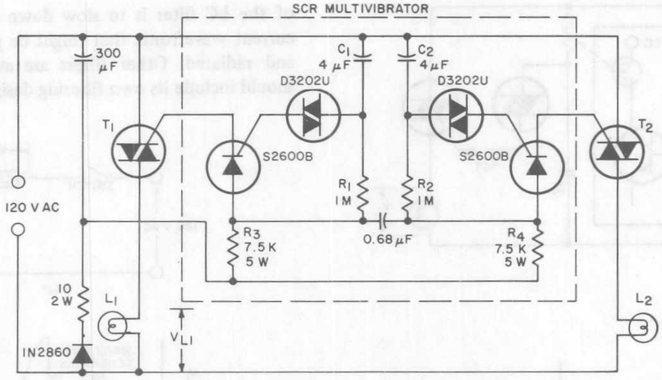


Fig. 14— Thyristor flasher.

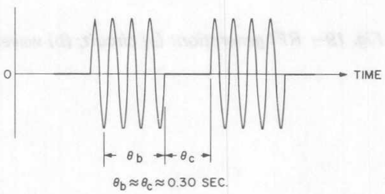


Fig. 15— Timing of thyristor flasher.

AC - DC ISOLATION

In the circuits shown thus far, either a triac or an IC is used to interface between the dc logic and the ac power circuitry. A number of other methods can be used to isolate these stages in a traffic controller. The circuit of Fig. 16 illustrates the use of a reed-type relay. When the relay is activated, the triac is gated in its I+ and III- modes and little power is dissipated in the gate circuit. Fig. 17 shows the use of a light source and photocell combination. Because the photocell is part of a single-time-constant circuit, it must have enough dark resistance to keep the voltage across C1 below 32 volts so that the diac does not switch and discharge the capacitor into the gate of the triac at all times. A pulse transformer can also be used for isolation, as shown in Fig. 18. A 5-kHz signal into the gate turns the triac on at initiation of the pulsing and keeps it on until the oscillator is stopped.

RFI SUPPRESSION

Radio-frequency interference (RFI) that can result from the fast triac switching of high power loads must be considered in traffic control circuits. When an ac load is switched on, as shown in Fig. 19, RFI is generated in the initial wavefront. This steep wavefront contains many harmonics that can be sustained by the circuit Q.

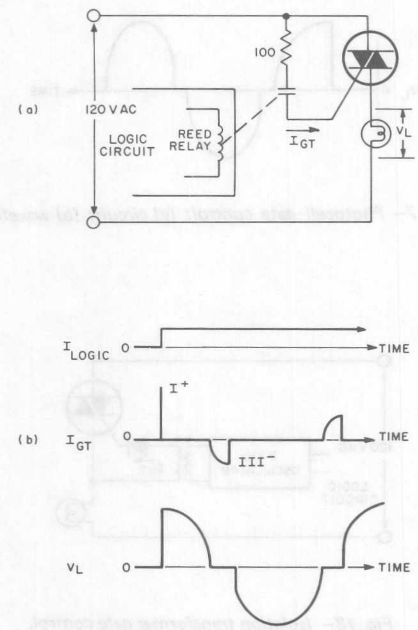


Fig. 16— (a) Circuit, and (b) waveforms of reed-relay gate control.

One method of reducing RFI is zero-voltage switching with resistive loads; thus, the circuits above that utilize the RCA-CA3059 IC inherently include RFI suppression. Circuits that do not use zero-voltage switching require external filters for RFI suppression. A typical filter used in conjunction with ac loads is portrayed in Fig. 20. The effect

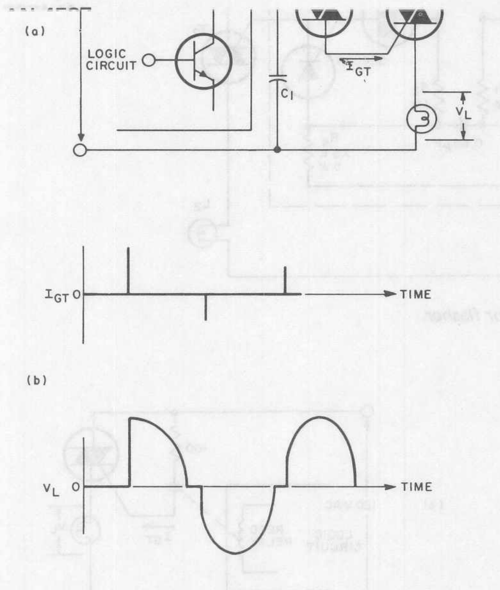


Fig. 17— Photocell gate control: (a) circuit; (b) waveforms.

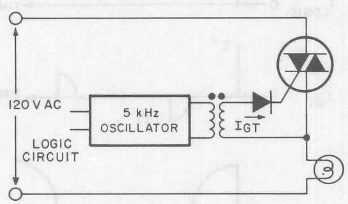


Fig. 18— Isolation transformer gate control.

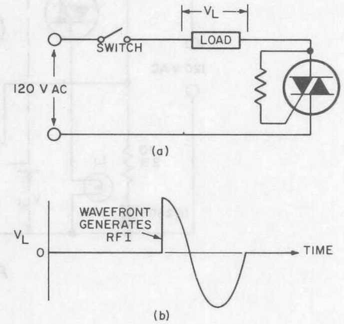


Fig. 19— RFI generation: (a) circuit; (b) waveform.

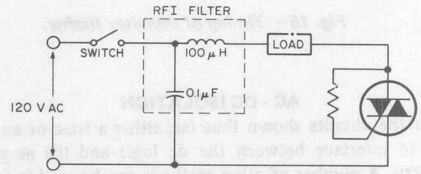


Fig. 20— RFI-suppression filter.

Analysis and Design of Snubber Networks for dv/dt Suppression in Thyristor Circuits

by J. E. Wojslawowicz

When a triac is used to control an inductive load, voltages with high rates of change (dv/dt) can be generated that can cause a non-gated turn-on of the triac. This false turn-on can occur if the dv/dt exceeds the critical rate of rise of commutation voltage of the triac, or if voltage ringing occurs that exceeds the blocking capability of the triac (V_{DROM}). The false triggering caused by these mechanisms results in a loss of control of power to the load; to assure reliable operation, therefore, it is necessary to provide means to suppress this dv/dt stress as it is commonly called. The simplest method of dv/dt suppression is the use of a series RC network across the main terminals of the triac. The design of this network, commonly called a snubber network, must take into account the peak voltage that can be allowed in the circuit, and the maximum dv/dt stress that the device can withstand. This Note analyzes the RC network design and presents graphs that allow a designer to select a snubber to fulfill his requirements.

Commutating dv/dt And False Turn-On

Fig. 1 shows a control triac in a typical connection with an ac power source and a load. The triac is a regenerative device; once it has been turned on, it continues to conduct until the principal current drops below a value that just supports the regeneration. This current level is called the holding current of the device. If the gate signal is removed before the principal current decreases below the holding current, the device turns off and regains its blocking capability.

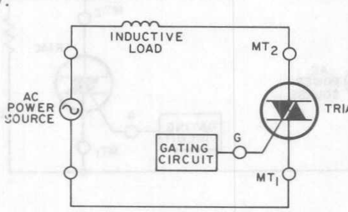


Fig. 1— Series connection of a triac, an inductive load, and an ac power source.

Fig. 2 shows the triac principal voltage and current waveforms when the load is resistive. If the gate signal is removed at time t_0, the device continues to conduct until the current attempts to reverse polarity. The device then undergoes a reverse recovery period, and thereafter must support a main terminal voltage of the reverse polarity that is equal to the source voltage. The rate of reapplication of this off-state voltage for a resistive load and a 120-volt 60-Hz source is typically 0.064 volt per microsecond if the stray inductance due to wiring is minimal. This rate of reapplication generally does not cause turn-on of the device.

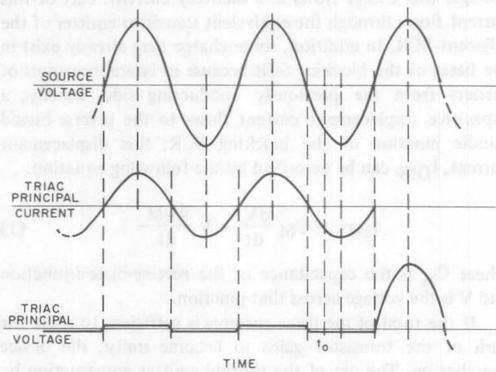


Fig. 2— Principal voltage and current for a triac in operation with a resistive load.

In a circuit with an inductive load the voltage leads the current by some phase angle ϕ as shown in Fig. 3. After the triac turns off it must block the reapplied instantaneous line voltage of the reverse polarity. Because the triac goes from the conducting state to the blocking state in a very short time, this voltage is reapplied very rapidly. The turn-off of the triac causes a rapid decay of current through the inductance, and thus produces an Ldi/dt voltage. This rapidly

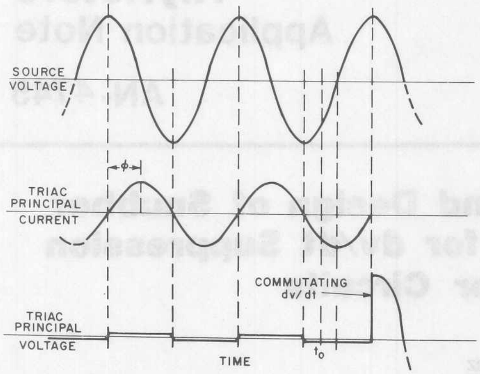


Fig. 3— Principal voltage and current for a triac in operation with an inductive load.

rising off-state voltage stress is impressed across the main terminals of the device and can cause it to turn on. Fig. 4 illustrates this false turn-on.

A triac analog that uses two silicon controlled rectifiers (SCR's) provides a simple understanding of how this dv/dt causes the device to turn on. The inverse parallel SCR analog of the triac is shown in Fig. 5(a), and a two-transistor analog of the SCR is shown in Fig. 5(b). At the end of the half cycle of on-state current conduction, some charge remains in the bases of the equivalent transistors that comprise the conducting SCR. Upon application of the opposite-quadrant off-state voltage, this charge flows as a recovery current. Part of this current flows through the equivalent transistor emitter of the adjacent SCR. In addition, some charge may already exist in the bases of the blocking SCR because of lateral transport of carriers from the previously conducting side. Finally, a capacitive displacement current flows to the reverse-biased middle junction of the blocking SCR; this displacement current, I_{DIS}, can be described by the following equation:

$$I_{DIS} = C_M \frac{dV}{dt} + V \frac{dC_M}{dt} \qquad (1)$$

where C_M is the capacitance of the reverse-biased junction and V is the voltage across that junction.

If the total of the three currents is sufficient to cause the sum of the transistor gains to become unity, the device switches on. The use of the shorted-emitter construction by RCA shunts some of the current away and thus permits a higher dv/dt stress to be placed across the device, but does not eliminate the current completely. The first two current flows are functions of device design and construction, but the displacement current flow can be controlled by use of an RC snubber network that limits the rate of reapplication of off-state voltage.

The snubber network, illustrated in Fig. 6, consists of a resistance R_S and a capacitance C_S placed in series across the main terminals of the device. For some snubber component values and some types of load, excessive ringing can occur in the circuit; this voltage ringing can exceed the blocking capability (V_{DROM}) of the device. Malfunction of the device is then caused by the inability of the triac to block the voltage even though it can withstand the dv/dt stress. An example of voltage ringing is shown in Fig. 7(a). Fig. 7(b) shows the same voltage on an expanded time scale.

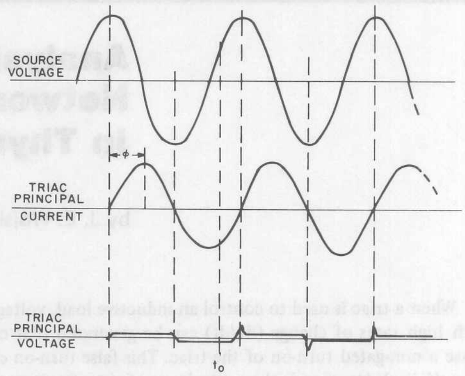


Fig. 4— Principal voltage and current curves showing triac malfunction that results from commutating dv/dt produced by inductive load.

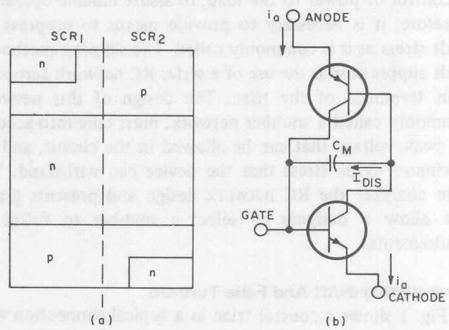


Fig. 5— (a) Two-SCR representation of a triac; (b) two-transistor model of an SCR, with junction capacitance shown.

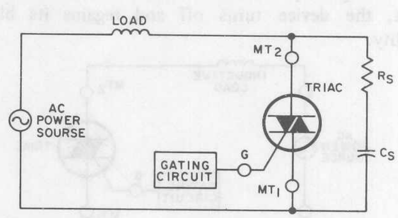
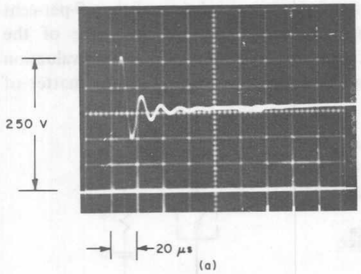


Fig. 6— Triac circuit using a snubber network of R_S and C_S connected across the triac.



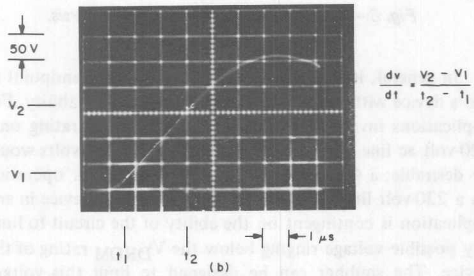


Fig. 7— (a) Ringing, caused by inductive load, in the principal voltage of triac; (b) principal voltage shown on an expanded scale.

Basic Circuit Analysis

The suppression network must be designed to limit the dv/dt stress and to have an acceptable voltage overshoot. Fig. 8 shows an equivalent circuit used for analysis, in which the triac has been replaced by an ideal switch. When the triac is in the blocking or non-conducting state, represented by the open switch, the circuit is a standard RLC series network driven by an ac voltage source. The following differential equation can be obtained by summing the voltage drops around the circuit:

$$(R_L + R_S)\, i(t) + L\frac{di(t)}{dt} + \frac{q_c(t)}{C_S} = V_M \sin(\omega t + \phi) \tag{2}$$

in which $i(t)$ is the instantaneous current after the switch opens, $q_c(t)$ is the instantaneous charge on the capacitor, V_M is the peak line voltage, and ϕ is the phase angle by which the voltage leads the current prior to opening of the switch. After differentiation and rearrangement, the equation becomes a standard second-order differential equation with constant coefficients. With the imposition of the boundary conditions that $i(0)=0$ and $q_c(0)=0$, the equation for the charge on the capacitor can be stated for the three circuit conditions as follows:

<u>Condition I</u>[1]: $(R_L + R_S)^2 < 4L/C$

$$q_c(t) = \frac{-|V_M|}{\omega |Z|}\cos(\omega t + \phi + \theta) + |Q_t|\, \epsilon^{-\alpha t} \sin(\beta t + \eta) \tag{3}$$

<u>Condition II</u>[2]: $(R_L + R_S)^2 = 4L/C$

$$q_c(t) = \frac{-|V_M|}{\omega |Z|}\cos(\omega t + \phi + \theta) + \epsilon^{-\alpha t}\left[(1 + \alpha t)\, q_d + i_d t\right] \tag{4}$$

<u>Condition III</u>[3]: $(R_L + R_S)^2 > 4L/C$

$$q_c(t) = \frac{-|V_M|}{\omega |Z|}\cos(\omega t + \phi + \theta) + \frac{\epsilon^{-\alpha t}}{\beta'}\left[(\alpha q_d + i_d t)\sinh \beta' t + \beta' q_d \cosh \beta' t\right] \tag{5}$$

The symbols used in these equations are defined as follows:

$$\phi = \tan^{-1}(\omega L/R_L) \tag{6}$$

$$\theta = -\tan^{-1}\left[\left(\omega L - \frac{1}{\omega C_S}\right)/(R_L + R_S)\right] \tag{7}$$

$$\alpha = \frac{R_L + R_S}{2L} \tag{8}$$

$$\beta' = \sqrt{\left(\frac{R_L + R_S}{2L}\right)^2 - \frac{1}{LC_S}} \tag{9}$$

$$\beta = \sqrt{\frac{1}{LC_S} - \left(\frac{R_L + R_S}{2L}\right)^2} \tag{10}$$

$$Z = (R_L + R_S) + j\left(\omega L - \frac{1}{\omega C_S}\right) \tag{11}$$

$$q_d = \frac{|V_M|}{\omega |Z|}\cos(\phi + \theta) + q_c(0) \tag{12}$$

$$i_d = i(0) - \frac{|V_M|}{|Z|}\sin(\phi + \theta) \tag{13}$$

$$|Q_t| = \sqrt{\left[\frac{\alpha q_d + i_d}{\beta}\right]^2 + q_d^2} \tag{14}$$

$$\eta = \tan^{-1}\left(\frac{\beta q_d}{\alpha q_d + i_d}\right) \tag{15}$$

The voltage across the device is determined by calculating the voltages across the snubber capacitor and resistor from the following fundamental relations:

$$v_{C_S}(t) = \frac{q_c(t)}{C_S} \tag{16}$$

$$v_{R_S}(t) = R_S \frac{dq_c(t)}{dt} \tag{17}$$

The sum of these two voltages then represents the instantaneous voltage across the triac. The following equations give the instantaneous voltage for the three circuit conditions:

Condition I: $(R_L + R_S)^2 < 4L/C$

$$v(t) = \frac{-|V_M|}{|Z|}\left[\frac{1}{\omega C_S}\cos(\omega t + \phi + \theta) - R_S \sin(\omega t + \phi + \theta)\right] + |Q_t|\epsilon^{-\alpha t}\left[\frac{1}{C_S}\sin(\beta t + \eta) + \frac{R_S}{\sqrt{LC_S}}\sin(\beta t + \eta + \psi)\right] \quad (18)$$

where ψ is defined by the following expression:

$$\psi = \tan^{-1}\left(\frac{\beta}{-\alpha}\right) \quad (19)$$

Condition II: $(R_L + R_S)^2 = 4L/C$

$$v(t) = \frac{-|V_M|}{|Z|}\left[\frac{1}{\omega C_S}\cos(\omega t + \phi + \theta) - R_S \sin(\omega t + \phi + \theta)\right] + \frac{1}{C_S}\left[(1 + \alpha t)\, q_d + i_d t\right]\epsilon^{-\alpha t} + R_S\left[(1 - \alpha t)\, i_d - \alpha^2 t q_d\right]\epsilon^{-\alpha t} \quad (20)$$

Condition III: $(R_L + R_S)^2 > 4L/C$

$$v(t) = \frac{-|V_M|}{|Z|}\left[\frac{1}{\omega C_S}\cos(\omega t + \phi + \theta) - R_S \sin(\omega t + \phi + \theta)\right] + \frac{\epsilon^{-\alpha t}}{\beta' C_s}\left[(\alpha q_d + i_d)\sinh\beta' t + \beta' q_d \cosh\beta' t\right] + R_S\epsilon^{-\alpha t}\left[\frac{-\alpha i_d - \frac{1}{LC_S}q_d}{\beta'}\sinh\beta' t + i_d\cosh\beta' t\right] \quad (21)$$

A computer is used to calculate the voltage across the snubber because hand calculation is time-consuming. The magnitude and time of occurrence of the peak voltage are found by numerical analysis, and then the values and times of the voltages at 10 per cent and 63 per cent of peak are calculated. These values are used to compute the dv/dt stress as defined by the following equation:

$$dv/dt = \frac{V_2 - V_1}{t_2 - t_1} \quad (22)$$

where V_1 and t_1 are the voltage and time of the 10-per-cent point and V_2 and t_2 are the voltage and time of the 63-per-cent point. This program therefore allows evaluation of various load and snubber combinations in a matter of minutes.

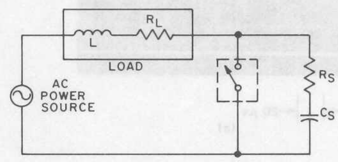


Fig. 8– Equivalent circuit used for analysis.

In general, it is most desirable from a cost standpoint to use a device with the lowest possible V_{DROM} capability. For applications involving the control of a load operating on a 120-volt ac line a device with a V_{DROM} of 200 volts would be desirable; a 400-volt device should be used for operation on a 220-volt line. The use of the lower-voltage device in any application is contingent on the ability of the circuit to limit any possible voltage ringing below the V_{DROM} rating of the device. The snubber can be designed to limit this voltage ringing during the post-commutation period to within this rating. Figs. 9 and 10 show the values of C_S and R_S that limit peak voltage across the triac to specific values. Fig. 9 allows the selection of snubber components that will limit the peak voltage of 200 volts for a zero-power-factor load at the desired dv/dt for an rms line voltage of 120 volts. Fig. 10 shows the components that limit the voltage to 400 volts when the rms line voltage is 220 volts.

Snubber Design Procedure

For use of the graphs, three things must be known: (1) the rms line voltage, (2) the rms load current, and (3) the allowable dv/dt. The following procedure is used to obtain the required snubber components:

(1) Draw a vertical line on the proper voltage graph at the load current.

(2) At the intersection of the vertical line and the dashed line that represents the allowable dv/dt, draw a horizontal line to the right vertical axis. Read the value of R_S from the right vertical axis.

(3) At the intersection of the vertical line and the solid line that represents the allowable dv/dt, draw a horizontal line to the left vertical axis. Read the value of C_S from the left vertical axis.

As an illustration of the above procedure. Fig. 9 is used to find snubber component values that limit the dv/dt stress to 5 volts per microsecond for a 40-ampere rms current in a 120-volt rms line. From Fig. 9, these values are R_s = 340 ohm and C_s = 0.18 microfarad.

As previously stated, these graphs were developed to limit the peak voltage for a zero-power-factor load. For the non-ideal load the graphs are used in the same fashion; a

reduction in the peak voltage following commutation and a slight reduction in the dv/dt stress are the only effects introduced by the non-ideal load. The reduction in the peak voltage excursion is caused by the decrease in instantaneous voltage at the time of commutation. As the power factor increases, the phase angle between the voltage and current decreases toward 0°. This decrease in the phase angle shifts the time of commutation in the half-cycle toward the zero-voltage crossing and thus reduces the instantaneous voltage. The reduction in the dv/dt stress is the result of both the reduction in the voltage at commutation and the increasing resistive impedance of the load.

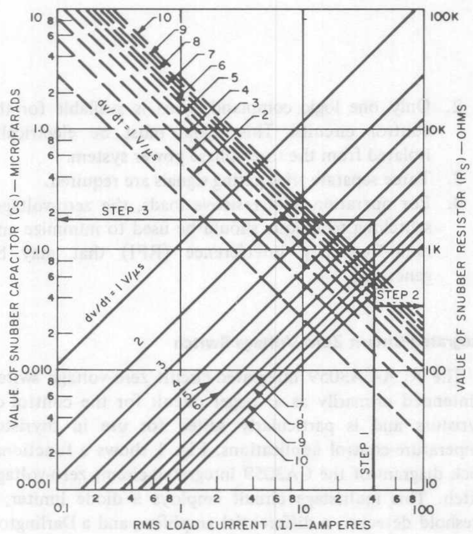


Fig. 9— Design curves for snubber that limits peak voltage to 200 volts for 120-volt ac line and zero power factor.

A numerical example shows how a load that is not purely inductive reduces the peak voltage after commutation. The snubber components for 8 volts per microsecond at an rms current of 22.7 amperes are found from Fig. 9 to be 960 ohms and 0.04 microfarad. If the load is purely inductive, the peak voltage is limited to 200 volts. If the load has the same current rating but a power factor of 0.7, this snubber network limits the peak voltage after commutation to 140 volts. The peak voltage is reduced because the instantaneous line voltage at the time of commutation is only 121 volts. The dv/dt stress is also slightly lower than the 8-volts-per-microsecond value. This example demonstrates that the design graphs of Figs. 9 and 10 can be used for loads having any power factor.

Because the selection of snubber components is dependent on circuit and device characteristics, values obtained may be impractical from a cost or size standpoint. In such a case, a triac with higher dv/dt capability or higher V_{DROM} rating should be used. A higher dv/dt capability allows selection of new snubber components to meet the size and/or cost requirements of the circuit. A higher V_{DROM} rating permits a higher peak voltage excursion that in general will allow selection of a smaller snubber capacitor and smaller resistor.

The circuit analysis described in this Note assumes the effects of the triac to be a minimum. Thus some error is introduced by neglect of the reverse recovery process and the displacement current. The additional current flow tends to increase the instantaneous dv/dt during the first few microseconds following commutation. The over-all effect is to increase slightly the average dv/dt stress across the device. This effect is most noticeable when the snubber capacitance is less than 0.001 microfarad. Selection of a snubber for a lower dv/dt stress limit will generally eliminate this problem.

Because the design of a snubber is contingent on the load, it is almost impossible to simulate and test every possible combination under actual operating conditions. It is advisable to measure the peak amplitude and rate of rise of voltage across the triac after a snubber has been selected.

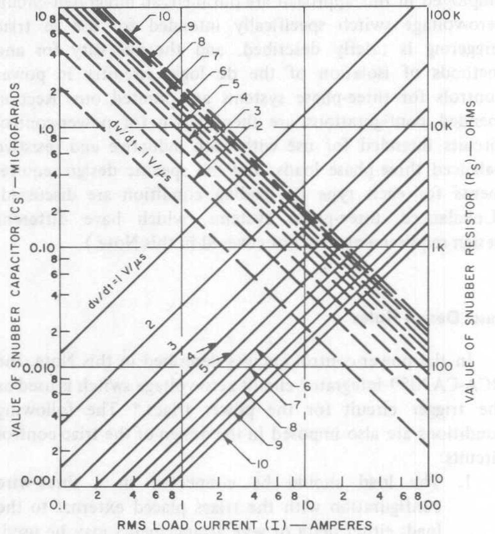


Fig. 10— Design curves for snubber that limits peak voltage to 400 volts for 220-volt ac line and zero power factor.

References

1. Myril B. Reed, Alternating Current Circuit Theory (New York: Harper & Brothers, 1948), pg. 276.
2. Ibid, pg. 284.
3. Ibid, pg. 284.

RCA Solid State Division

Thyristors
Application Note AN-6054

Triac Power Controls for Three-Phase Systems

by J. Yellin

The growing demand for solid-state switching of ac power in heating controls and other industrial applications has resulted in the increasing use of triac circuits in the control of three-phase power. This Note explains a basic approach to the design of triac control circuits for use in the switching of three-phase power. The basic design rules employed in this approach are outlined, an integrated-circuit zero-voltage switch specifically intended for use in triac triggering is briefly described, and the necessity for and methods of isolation of the dc logic circuitry in power controls for three-phase systems are pointed out. Recommended configurations are then shown for power-control circuits intended for use with both inductive and resistive balanced three-phase loads, and the specific design requirements for each type of loading condition are discussed. (Unbalanced three-phase systems, which have different design requirements, are not covered in this Note.)

Basic Design Rules

In the power-control circuits described in this Note, the RCA-CA3059 integrated-circuit zero-voltage switch is used as the trigger circuit for the power triacs.* The following conditions are also imposed in the design of the triac control circuits:

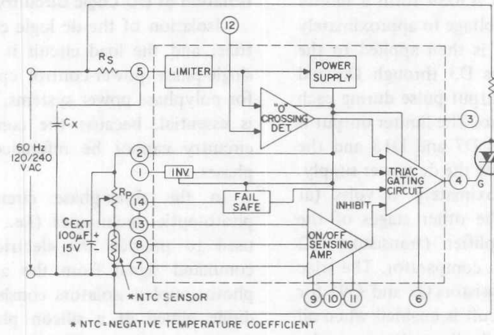
1. The load should be connected in a three-wire configuration with the triacs placed external to the load; either delta or wye arrangements may be used. Four-wire loads in wye configurations can be handled as three independent single-phase systems. Delta configurations in which a triac is connected within each phase rather than in the incoming lines can also be handled as three independent single-phase systems.
2. Only one logic command signal is available for the control circuits. This signal must be electrically isolated from the three-phase power system.
3. Three separate triac gating signals are required.
4. For operation with resistive loads, the zero-voltage-switching technique should be used to minimize any radio-frequency interference (RFI) that may be generated.

Integrated-Circuit Zero-Voltage Switch

The RCA-CA3059 integrated-circuit zero-voltage switch is intended primarily as a trigger circuit for the control of thyristors and is particularly suited for use in thyristor temperature-control applications. Fig. 1 shows a functional block diagram of the CA3059 integrated-circuit zero-voltage switch. This multistage circuit employs a diode limiter, a threshold detector, a differential amplifier, and a Darlington output driver to provide the basic switching action. The dc supply voltage for these stages is supplied by an internal zener-diode-regulated power supply that has sufficient current capability to drive external circuit elements, such as transistors and other integrated circuits. The trigger pulse developed by this circuit can be applied directly to the gate of an SCR or a triac. A built-in fail-safe circuit inhibits the application of these pulses to the thyristor gate circuit in the event that the external sensor for the integrated-circuit switch should be inadvertently opened or shorted. The CA3059 may be employed as either an on-off type of controller or a proportional controller, depending upon the degree of temperature regulation required.

Fig. 2 shows the schematic diagram for the CA3059 integrated circuit. Any triac that is driven directly from the output terminal of this circuit should be characterized for operation in the I(+) or III(+) triggering modes, i.e., with positive gate current (current flows into the gate for both polarities of the applied ac voltage). The circuit operates directly from a 50-, 60-, or 400-Hz ac line voltage of 120 to 277 volts.

*In addition to the CA3059, the RCA-CA3058 and -CA3079 integrated-circuit zero-voltage switches may also be used for triac triggering in the power-control circuits. All information given on the CA3059 in this Note is, in general, equally applicable to the CA3058 and CA3079.



AC Input Voltage (50/60 or 400 Hz) V AC	Input Series Resistor (R_S) k Ω	Dissipation Rating for R_S W
24	2	0.5
120	10	2
208/230	20	4
277	25	5

Fig. 1—Functional block diagram of the CA3059 integrated-circuit zero-voltage switch.

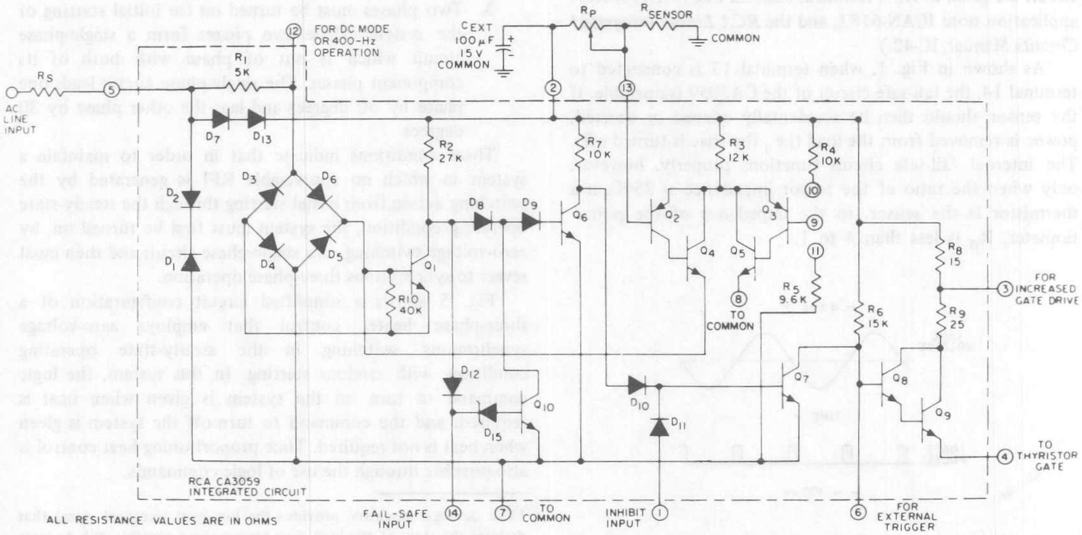


Fig. 2—Circuit diagram for the CA3059 zero-voltage switch.

transistor Q1), which generates an output pulse during each passage of the line voltage through zero. The limiter output is also applied to the rectifying diodes D7 and D13 and the external capacitor C_{EXT} that comprise the dc power supply. The power supply provides approximately 6 volts (at terminal 2) as the dc supply to the other stages of the CA3059. The on/off sensing amplifier (transistors Q2 through Q5) is basically a differential comparator. The triac gating circuit contains a driver (transistors Q8 and Q9) for direct triac triggering. The gating circuit is enabled when all the inputs are at a high voltage, i.e., the line voltage must be approximately zero volts, the sensing-amplifier output must be "high", the external voltage to terminal 1 must be a logical "1", and the output of the fail-safe circuit must be "high".

Fig. 3 shows the position and width of the pulses supplied to the gate of a thyristor with respect to the incoming ac line voltage. The CA3059 can supply sufficient gate voltage and current to trigger most RCA thyristors at ambient temperatures of 25°C. However, under worst-case conditions (i.e., at low ambient-temperature extremes and maximum trigger requirements), selection of the higher-current thyristors may be necessary for particular applications. (The RCA technical bulletin File No. 406 lists triacs designed for use with the integrated-circuit zero-voltage switch as the triggering circuit. Detailed information on the operating characteristics and capabilities of this integrated circuit are given in RCA technical bulletin File No. 490, RCA application note ICAN-6182, and the *RCA Linear Integrated Circuits* Manual, IC-42.)

As shown in Fig. 1, when terminal 13 is connected to terminal 14, the fail-safe circuit of the CA3059 is operable. If the sensor should then be accidentally opened or shorted, power is removed from the load (i.e., the triac is turned off). The internal fail-safe circuit functions properly, however, only when the ratio of the sensor impedance at 25°C, if a thermistor is the sensor, to the impedance of the potentiometer. R_p is less than 4 to 1.

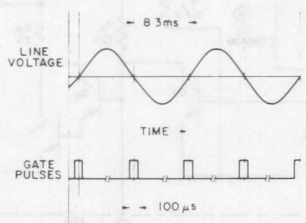


Fig. 3– Timing relationship between the output pulses of the CA3059 and the ac line voltage (pulse duration shown is a typical value for operation from a 120-volt 60-Hz line voltage).

for polyphase power systems, however, this type of isolation is essential, because the common point of the dc logic circuitry cannot be referenced to a common line in all phases.

In the three-phase circuits described in this Note, photo-optic techniques (i.e., photo-coupled isolators) are used to provide the electrical isolation of the dc logic command signal from the ac circuits and the load. The photo-coupled isolators consist of an infrared light-emitting diode aimed at a silicon photo transistor, coupled in a common package. The light-emitting diode is the input section, and the photo transistor is the output section. The two components provide a voltage isolation typically of 1500 volts. Other isolation techniques, such as pulse transformers, magnetoresistors, or reed relays, can also be used with some circuit modifications.

Resistive Loads

Fig. 4 illustrates the basic phase relationships of a balanced three-phase resistive load, such as may be used in heater applications, in which the application of load power is controlled by zero-voltage switching. The following conditions are inherent in this type of application:

1. The phases are 120 degrees apart; consequently, all three phases cannot be switched on simultaneously at zero voltage.
2. A single phase of a wye configuration type of three-wire system cannot be turned on.
3. Two phases must be turned on for initial starting of the system. These two phases form a single-phase circuit which is out of phase with both of its component phases. The single-phase circuit leads one phase by 30 degrees and lags the other phase by 30 degrees.

These conditions indicate that in order to maintain a system in which no appreciable RFI is generated by the switching action from initial starting through the steady-state operating condition, the system must first be turned on, by zero-voltage switching, as a single-phase circuit and then must revert to synchronous three-phase operation.

Fig. 5 shows a simplified circuit configuration of a three-phase heater control that employs zero-voltage synchronous switching in the steady-state operating condition, with random starting. In this system, the logic command to turn on the system is given when heat is required, and the command to turn off the system is given when heat is not required. Time proportioning heat control is also possible through the use of logic commands.

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*The dc logic circuitry provides the low-level electrical signal that dictates the state of the load. For temperature controls, the dc logic circuitry includes a temperature sensor for feedback. The RCA integrated-circuit zero-voltage switch, when operated in the dc mode with some additional circuitry, can replace the dc logic circuitry for temperature controls.

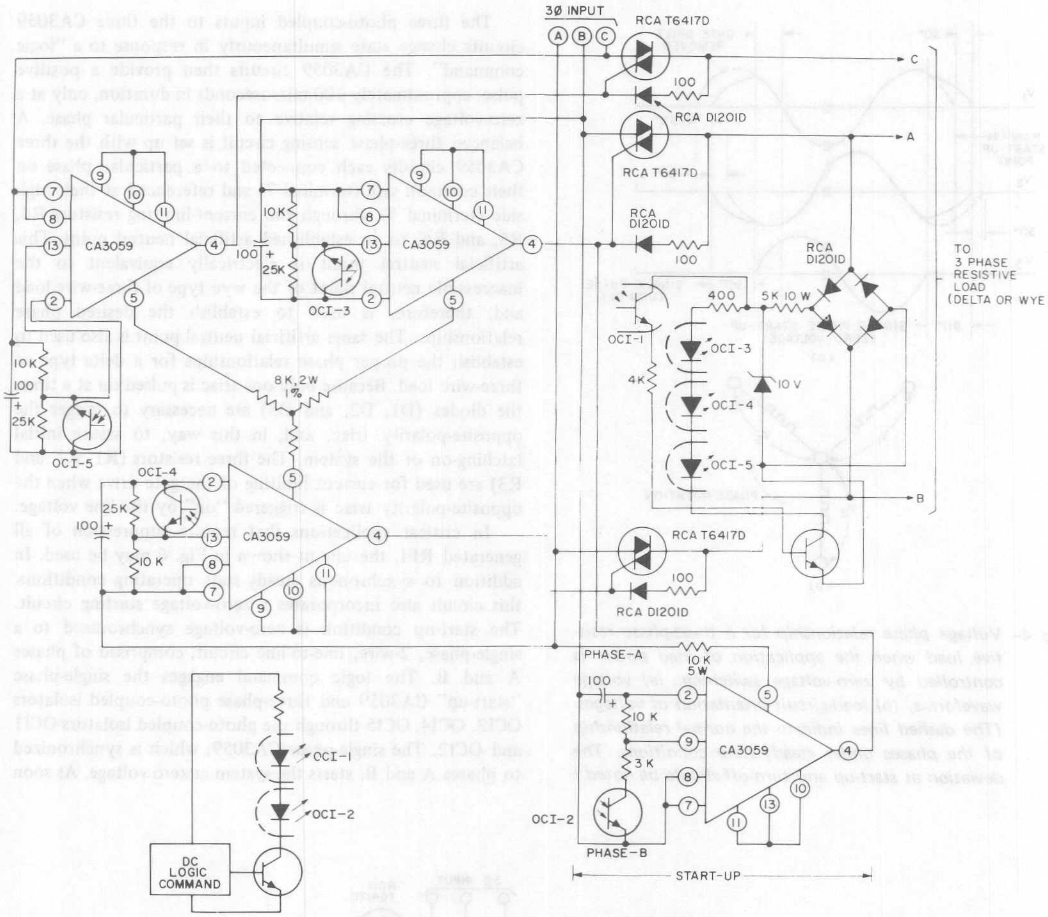


Fig. 6–Three-phase power control that employs zero-voltage synchronous switching both for steady-state operation and for starting.

as start-up is accomplished, the three photo-coupled isolators OCI3, OCI4, and OCI5 take control, and three-phase synchronization begins. When the "logic command" is turned off, all control is ended, and the triacs automatically turn off when the sine-wave current decreases to zero. Once the first phase turns off, the other two will turn off simultaneously, 90° later, as a single-phase line-to-line circuit, as is apparent from Fig. 4.

Inductive Loads

For inductive loads, zero-voltage turn-on is not generally required because the inductive current cannot increase instantaneously; therefore, the amount of RFI generated is usually negligible. Also, because of the lagging nature of the inductive current, the triacs cannot be pulse-fired at zero voltage. There are several ways in which the CA3059 may be interfaced to a triac for inductive-load applications. The most direct approach is to use the CA3059 in the dc mode, i.e., to provide a continuous dc output instead of pulses at points of zero-voltage crossing. This mode of operation is accomplished by connection of terminal 12 to terminal 7, as shown in Fig. 7. The output of the CA3059 should also be limited to approximately 5 milliamperes in the dc mode by the 750-ohm series resistor. Use of a triac such as the RCA T2301D is recommended for this application. Terminal 3 is connected to terminal 2 to limit the steady-state power

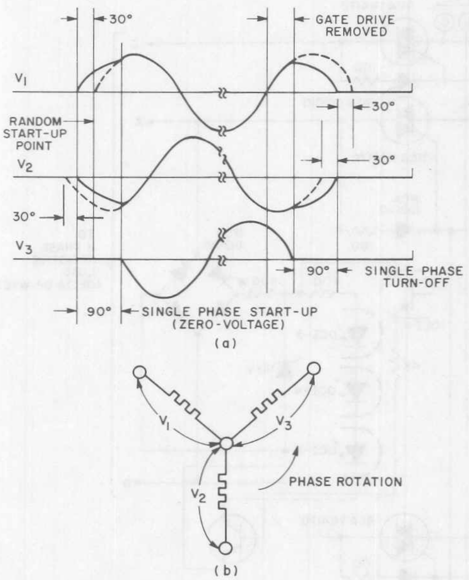


Fig. 4– Voltage phase relationship for a three-phase resistive load when the application of load power is controlled by zero-voltage switching: (a) voltage waveforms, (b) load-circuit orientation of voltages. (The dashed lines indicate the normal relationship of the phases under steady-state conditions. The deviation at start-up and turn-off should be noted.)

The three photo-coupled inputs to the three CA3059 circuits change state simultaneously in response to a "logic command". The CA3059 circuits then provide a positive pulse, approximately 100 microseconds in duration, only at a zero-voltage crossing relative to their particular phase. A balanced three-phase sensing circuit is set up with the three CA3059 circuits each connected to a particular phase on their common side (terminal 7) and referenced at their high side (terminal 5), through the current-limiting resistors R4, R5, and R6, to an established artificial neutral point. This artificial neutral point is electrically equivalent to the inaccessible neutral point of the wye type of three-wire load and, therefore, is used to establish the desired phase relationships. The same artificial neutral point is also used to establish the proper phase relationships for a delta type of three-wire load. Because only one triac is pulsed on at a time, the diodes (D1, D2, and D3) are necessary to trigger the opposite-polarity triac, and, in this way, to assure initial latching-on of the system. The three resistors (R1, R2, and R3) are used for current limiting of the gate drive when the opposite-polarity triac is triggered "on" by the line voltage.

In critical applications that require suppression of all generated RFI, the circuit shown in Fig. 6 may be used. In addition to synchronous steady-state operating conditions. this circuit also incorporates a zero-voltage starting circuit. The start-up condition is zero-voltage synchronized to a single-phase, 2-wire, line-to-line circuit, comprised of phases A and B. The logic command engages the single-phase "start-up" CA3059 and three-phase photo-coupled isolators OCI3, OCI4, OCI5 through the photo-coupled isolators OCI1 and OCI2. The single-phase CA3059, which is synchronized to phases A and B, starts the system at zero voltage. As soon

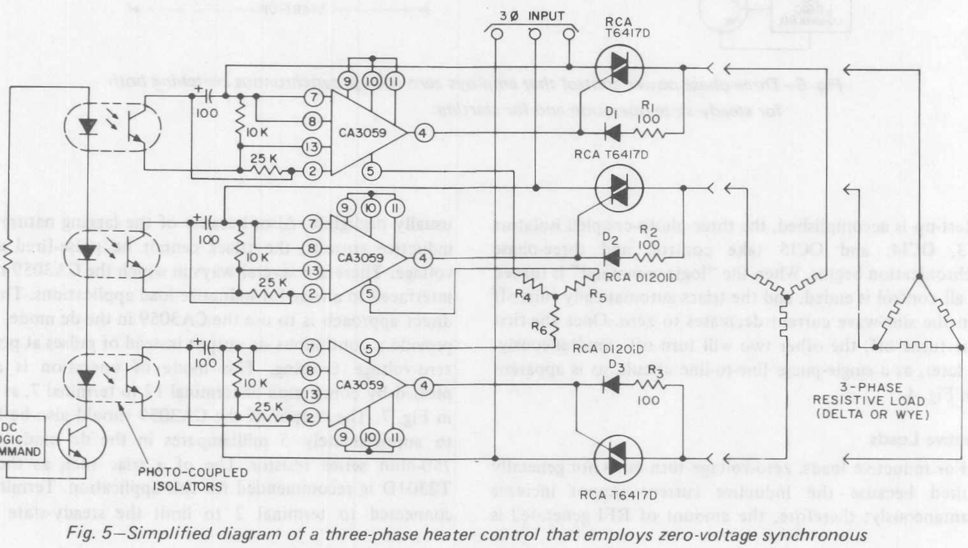


Fig. 5–Simplified diagram of a three-phase heater control that employs zero-voltage synchronous switching in the steady-state operating conditions.

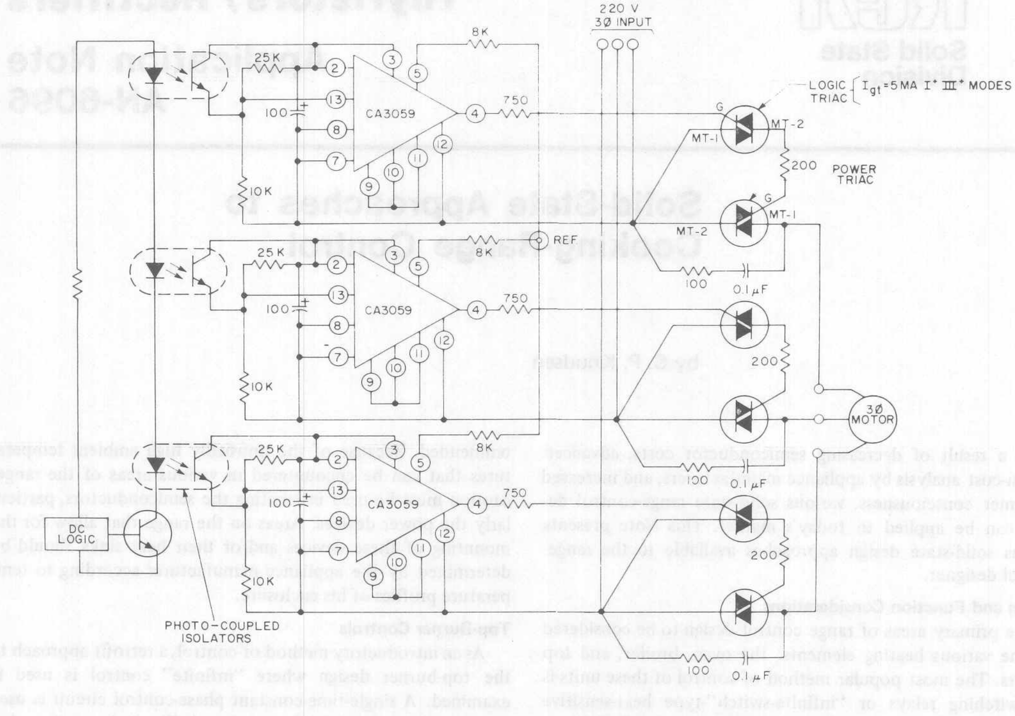


Fig. 7—Triac three-phase control circuit for an inductive load, i.e., three-phase motor.

dissipation within the CA3059. For most three-phase inductive load applications, the current-handling capability of the T2301D triac (2.5 amperes) is not sufficient. Therefore, the T2301D is used as a trigger triac to turn on any other currently available power triac that may be used. The trigger triac is used only to provide trigger pulses to the gate of the power triac (one pulse per half cycle); the power dissipation in this device, therefore, will be minimal.

Simplified circuits using pulse transformers and reed relays will also work quite satisfactorily in this type of application. The RC networks across the three power triacs are used for suppression of the commutating dv/dt when the circuit operates into inductive loads. (A detailed explanation of commutating dv/dt is provided in the basic discussion of thyristors in the *RCA Solid-State Power Circuits Designer's Handbook*, SP-52.)

Solid-State Approaches to Cooking-Range Control

by C. P. Knudsen

As a result of decreasing semiconductor costs, advanced system-cost analysis by appliance manufacturers, and increased consumer consciousness, various solid-state range-control designs can be applied to today's market. This Note presents various solid-state design approaches available to the range-control designer.

Design and Function Considerations

The primary areas of range control design to be considered are the various heating elements: the oven, broiler, and top burners. The most popular method of control of these units is by switching relays or "infinite-switch"-type heat-sensitive switches. Such controls generate radio-frequency interference, RFI, and can have limited life with respect to switching cycles because of contact failures. In addition, the nest of wiring usually needed to interconnect the incoming power line and the various independent loads results in substantial labor costs and possible substantial in-line reworking of ranges to accommodate design changes or failures. Calibration of these controls is generally cumbersome and time consuming because multiple settings are usually involved. However, from the standpoint of parts cost, the control is acceptable.

Semiconductor costs have been decreasing, and are approaching electromechanical-component costs; however, to justify the use of solid-state controls, cost factors other than actual parts costs must be considered. The reliability and the ease of handling of solid-state controls add to their dependable operation and desirability. Dependability can be measured in fewer in-line design corrections and possibly fewer calibrations, and, in turn, lower manufacturing costs. Lower manufacturing costs coupled with the ease of handling of printed circuit boards, which eliminate the nest of wiring, represent a further over-all system-cost reduction.

Other advantages of solid-state-control designs are manifest in their ability to accept design change or add-on designs to satisfy a customer's desire for improved products. For example, the self-cleaning feature is easily incorporated in the various oven controls; this feature is discussed in detail below.

Before any particular design approaches are discussed, a review of some of the characteristics of the devices used is recommended. Because of the unusually high ambient temperatures that can be encountered in various areas of the range, caution must be used in locating the semiconductors, particularly the power devices. Areas on the range that allow for the mounting of these devices and/or their heat sinks should be determined by the appliance manufacturer according to temperature profiles of his enclosure.

Top-Burner Controls

As an introductory method of control, a retrofit approach to the top-burner design where "infinite" control is used is examined. A single-time-constant phase-control circuit is used on each burner as the infinite control. Fig. 1 shows the schematic diagram of the circuit; Fig. 2 shows the various wave-

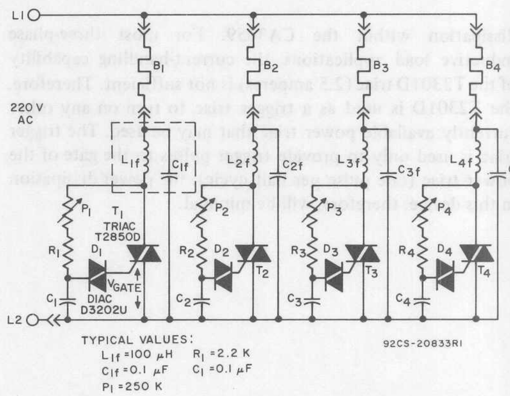


Fig. 1— Schematic diagram of retrofit-type top-burner control.

forms for the circuit. Because each heater-control circuit is identical, an examination of one, B_1, is sufficient for an understanding of all of the circuits. Potentiometer P_1, resistor R_1, and capacitor C_1 form a 60-Hz voltage divider in which high values of resistance for P_1 limit the peak voltage swing on C_1. The diac, which is a three-layer, p-n-p device, exhibits a high impedance until a peak voltage of approximately 32 volts is applied across it. At this time it displays a negative resistance.

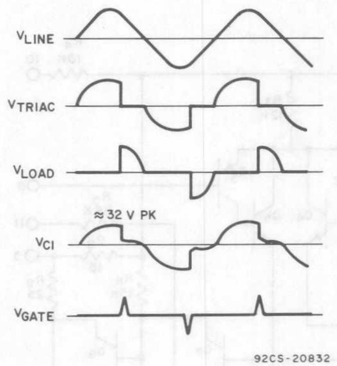


Fig. 2– Waveforms for the circuit of Fig. 1.

Therefore, if the potentiometer is set to allow capacitor C_1 to charge up to 32 volts peak, the capacitor discharges through the diac into the gate of the triac and turns the triac on to its low-impedance state. This action is repeated every half cycle. L_{1f} and C_{1f} are included to suppress the RFI generated by the switching wavefront of the triac.

This type of circuit is a retrofit design, but it has several disadvantages. These disadvantages include cost, the need for RFI filtering (a substantial part of the total cost), and the need for considerable hand wiring, as the bulky discrete components do not warrant printed-circuit-board mounting. However, infinite-switch-type control of the burners is accomplished, and the feasibility of solid-state device use in the control design is demonstrated.

Oven/Broiler Controls

Fig. 1 shows that the triac can be used to switch the burner elements without arcing or contact bounce, but the resulting "clean" waveform, Fig. 2, still has a high-frequency content in the AM broadcast band. To suppress this nuisance, a costly RFI filter must be incorporated in the design. The triac can still be utilized, however, by using another circuit approach, zero-voltage switching, ZVS, that can switch the heavy resistive loads with minimized RFI generation.

Zero-voltage switching is demonstrated in the oven control circuit shown in Fig. 3. In this circuit, a sensor element is included in the oven to provide a closed-loop system for accurate control of the oven temperature. The RCA CA3059[1,2] is used to accomplish the zero-voltage logic switching; the functional block diagram for the CA3059 is shown in Fig. 4.*

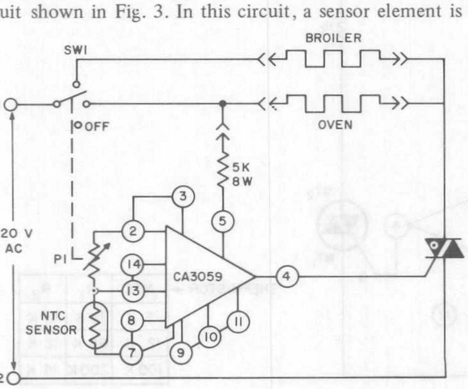


Fig. 3– Schematic diagram of basic oven control.

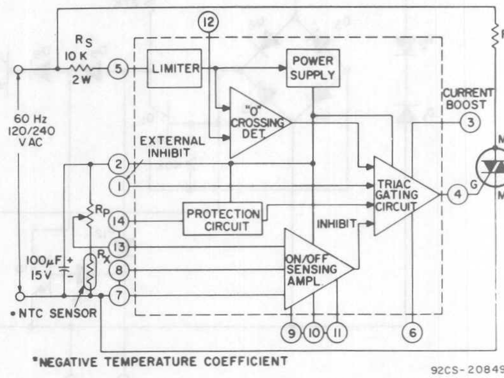


Fig. 4– Functional block diagram of CA3059 integrated-circuit zero-voltage switch.

The limiter stage of the CA3059 clips the incoming ac line voltage to approximately ±8 volts. This signal is then applied to the zero-voltage-crossing detector, which generates an output pulse during each passage of the line voltage through zero. The limiter output is also applied to a rectifying diode and an external capacitor that comprise the dc power supply. The power supply provides approximately 6 volts, as the V_{CC} supply, to the other stages of the CA3059. The on/off sensing amplifier is basically a differential comparator. The triac gating circuit contains a driver for direct triac triggering. The gating circuit is enabled when all the inputs are at a high voltage; i.e., the line voltage must be approximately zero volts, the sensing-amplifier output must be high, the external voltage to terminal 1 must be a logical 1, and the output of the fail-safe circuit must be high.

Fig. 5 shows the circuit diagram of the CA3059. The zero-voltage threshold detector consists of diodes D_3, D_4, D_5, and D_6, and transistor Q_1. The differential amplifier consists of transistor-pairs Q_2–Q_4 and Q_3–Q_5. Transistors Q_1, Q_6, Q_7, Q_8, and Q_9 comprise the triac gating circuit and driver stage. Diode D_{12}, zener-diode D_{15}, and transistor Q_{10} constitute the fail-safe circuit. The power supply consists of diodes D_7 and D_{13} and an external resistor and capacitor connected to terminals 5 and 2, respectively, and to ground through pin 7. If transistor pair Q_2–Q_4 and transistor Q_1 are turned off, an output appears at terminal 4. Transistor Q_1 is in the off state if the incoming line voltage is less than approximately the sum of the voltage drops across three silicon diodes (2.1 volts) for either the positive or negative excursion of the line voltage. Transistor pair Q_2–Q_4 is off if the voltage across the sensor, connected from terminals 13 to 7, exceeds the reference voltage from 9 to 7. If either of these conditions is not satisfied, pulses are not supplied to terminal 4. Fail-safe operation requires that terminal 13 be connected to terminal 14. The addition of

* The CA3079 can be interchanged with the CA3059 in many applications, as demonstrated in this Note.

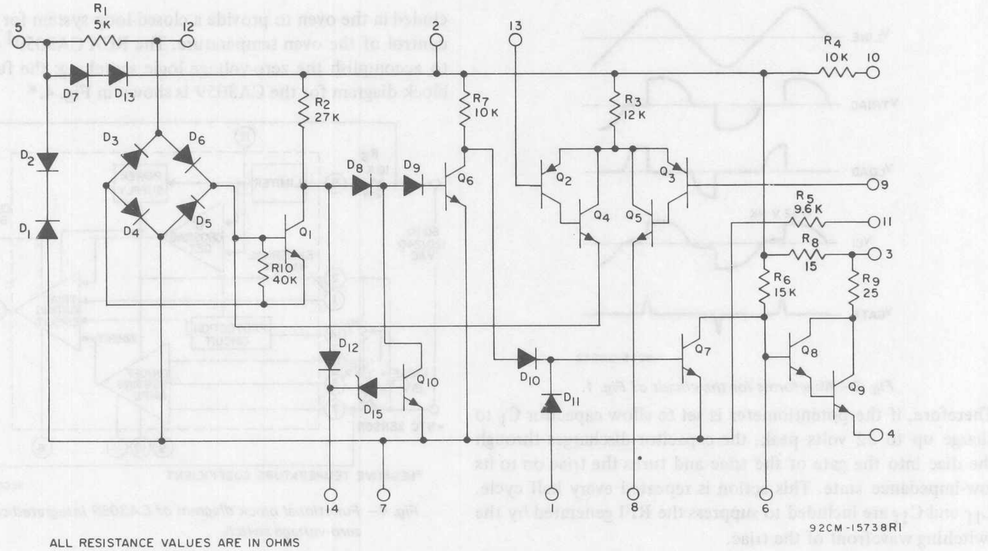
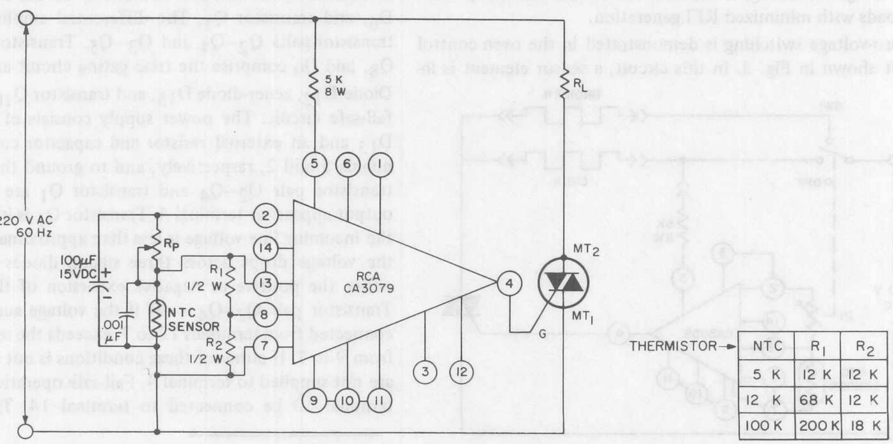


Fig. 5– Schematic diagram of CA3059 zero-voltage switch.

hysteresis and the elimination of half-cycling can be achieved by a resistive voltage divider connected from terminals 13 to 8 and from 8 to 7.

As shown in Fig. 3, the temperature of the oven can be adjusted by means of P_1, which acts, along with the sensor, as a voltage divider at terminal 13. The voltage at terminal 13 is compared to the fixed bias at terminal 9 which is set by internal resistors R_4 and R_5. When the oven is cold and the resistance of the sensor is high, Q_2 and Q_4 are off, a pulse of gate current is applied to the triac, and heat is applied to the oven. Conversely, as the desired temperature is reached, the bias at terminal 13 turns the triac off. The closed-loop feature then cycles the oven element on and off to maintain the desired temperature to approximately ±2°C of the set value. Also, as has been noted, external resistors between terminals 13 and 8, and 7 and 8, can be used to vary this temperature and provide hysteresis. In Fig. 6, a circuit that provides approximately 10-per-cent hysteresis is demonstrated.



NTC	R_1	R_2
5 K	12 K	12 K
12 K	68 K	12 K
100 K	200 K	18 K

Fig. 6– CA3079 on-off controller with hysteresis. 92CS-20841

In addition to allowing the selection of a hysteresis value, the flexibility of the control circuit permits incorporation of other features. A PTC sensor is readily used by interchanging terminals 9 and 13 of Fig. 3 and substituting the PTC for the NTC sensor. Note that in both cases the sensor element is directly returned to the system ground or common, as is often desired. Terminals 9, 10, and 11, Fig. 3, can be connected by external resistors to provide for a variety of biasing, e.g., to match a lower-resistance sensor for which the switching point voltage has been reduced to maintain the same sensor current.

To accommodate the self-cleaning feature, external switching, which enables both broiler and oven units to be paralleled, can easily be incorporated in the design. Of course, the potentiometer must be capable of a setting such that the sensor, which must be characterized for the high, self-clean temperature, can monitor and establish control of the high-temperature, self-clean mode. The ease with which this self-clean mode can be added makes the over-all solid-state system cost-competitive with electromechanical systems of comparable capability. In addition, the system incorporates solid-state reliability while being neater, more easily calibrated, and containing less-costly system wiring.

Low-Resistance Sensor

The circuit of Fig. 3 performs well with sensor values in the 5- to 10-kilohm range, and is used widely in home comfort controls. Although PTC sensors rated at 5 kilohms are available, the existing sensors in ovens are usually of a much lower value. The circuit depicted in Fig. 7 is offered to accommodate these

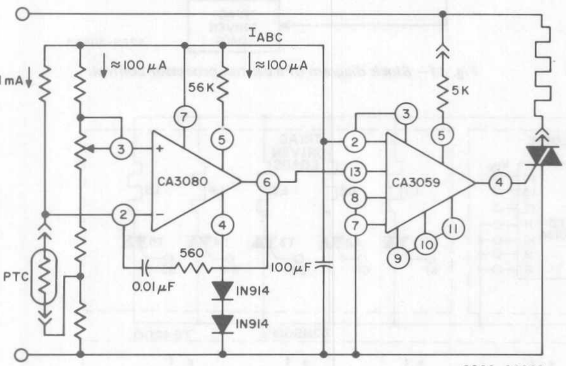


Fig. 7– Schematic diagram of circuit for use with low-resistance sensor.

inexpensive metal-wound sensors. A schematic diagram of the RCA CA3080, the operational transconductance amplifier used in Fig. 7, is shown in Fig. 8.[3] With an amplifier bias current, I_{ABC}, of 100 microamperes, a forward transconductance of 2 millimhos is achieved in this configuration. The CA3080 switches when the voltage at terminal 2 exceeds the voltage at terminal 3. This action allows the sink current, I_s, to flow from terminal 13 of the CA3059 (the input impedance to terminal 13 of the CA3059 is approximately 50 kilohms); gate pulses are no longer applied to the triac because Q_2 of the CA3059 is on. Hence, if the PTC sensor is cold, i.e., in the low resistance state, the load is energized. When the temperature of the PTC sensor increases to the desired temperature, the sensor enters the high resistance state, the voltage on terminal 2 becomes greater than that on terminal 3, and the triac switches the load off. Further cycling depends on the voltage across the sensor. Hence, very low values of sensor and potentiometer resistance can be used in conjunction with the CA3059 power supply without causing adverse loading effects and impairing system performance.

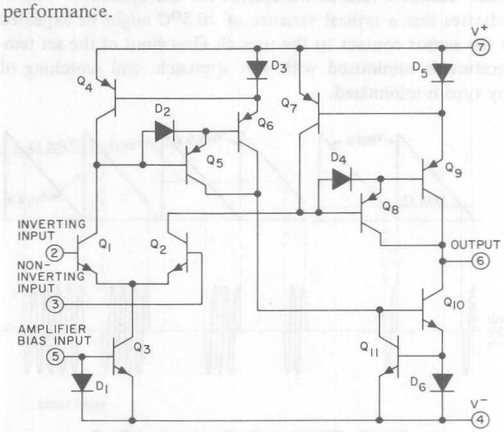


Fig. 8– Schematic diagram of the CA3080. 92CS-17587

Proportional Zero-Voltage Switching

Zero-voltage switching control can be extended to applications in which it is desirable to have constant control of the temperature and a minimization of system hysteresis. A closed-loop top-burner control in which the temperature of the cooking utensil is sensed and maintained at a particular value is a good example of such an application; the circuit for this control is shown in Fig. 9. In the circuit, a unijunction oscillator is outboarded from the basic control by means of the internal power supply of the RCA CA3079. The output of this ramp generator is applied to terminal 9 of the CA3079 and establishes a varied reference to the differential amplifier.

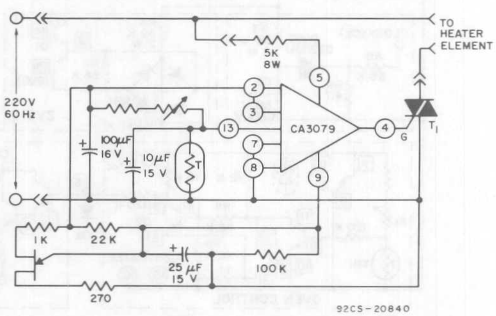


Fig. 9– Schematic diagram of proportional zero-voltage-switching control.

hot sensor. For precise temperature regulation, the time base of the ramp should be shorter than the thermal time constant of the system but longer than the period of the 60-Hz line. Fig. 10, which contains various waveforms for the system of Fig. 9, indicates that a typical variance of ±0.5°C might be expected at the sensor contact to the utensil. Overshoot of the set temperature is minimized with this approach, and scorching of any type is minimized.

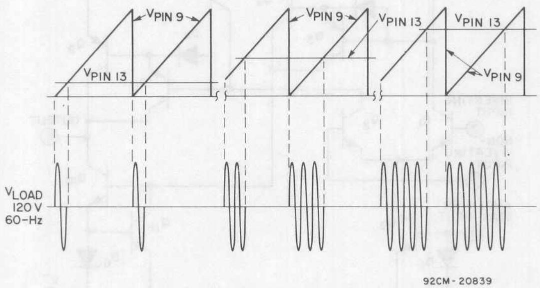


Fig. 10– Waveforms for the circuit of Fig. 9.

Now that the feasibility of a solid-state control for the range has been established, the various approaches can be joined and a system constructed. The phase-control circuit could be used for three top burners, the proportional control as cited above.

Central-Processor

Since the phase-control top-burner arrangement of Fig. 1 requires excessive handling in construction and does not lend itself to printed-circuit-board construction, it is recommended that a more compact, less expensive, total printed-circuit-board approach to the range control be investigated. Further, in order to cut system costs, is recommended that similar circuit functions be multiplexed or shared as much as possible in one area in the circuit. A design that meets these requirements is shown in the block diagram of Fig. 11 and the schematic diagram of Fig. 12. The top burners L1, L2, L3, and L4

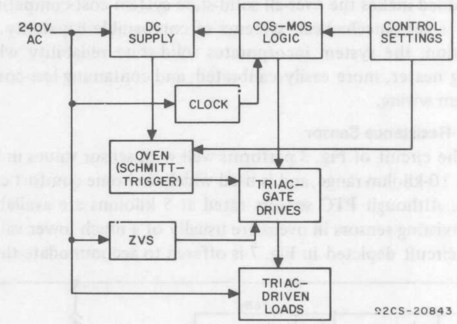


Fig. 11– Block diagram of a central-processor control.

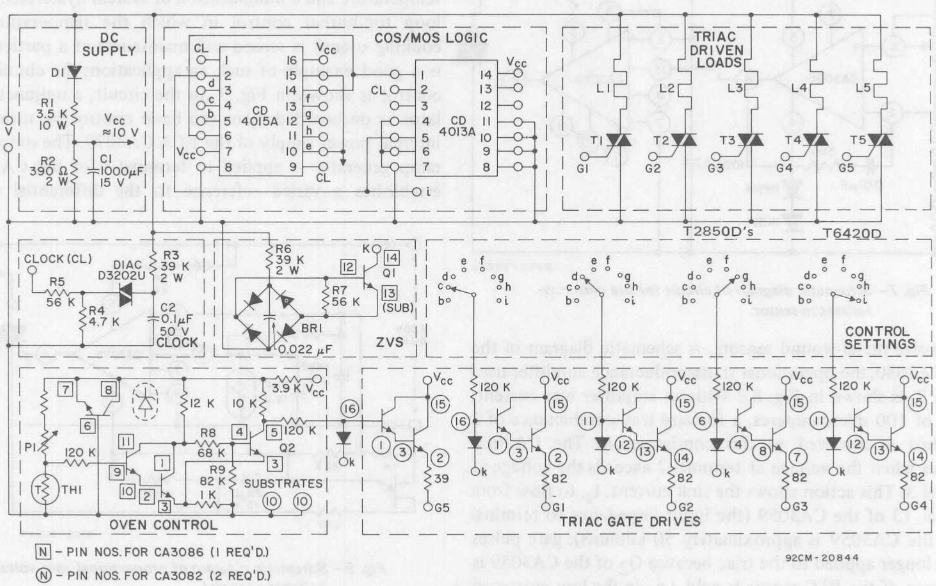


Fig. 12– Schematic diagram of the central-processor control of Fig. 11.

(Fig. 12) are all controlled by the single logic bank of COS/MOS circuitry composed of the RCA CD4013A and the RCA CD4015A; the logic diagrams of these devices are shown in Figs. 13 and 14.

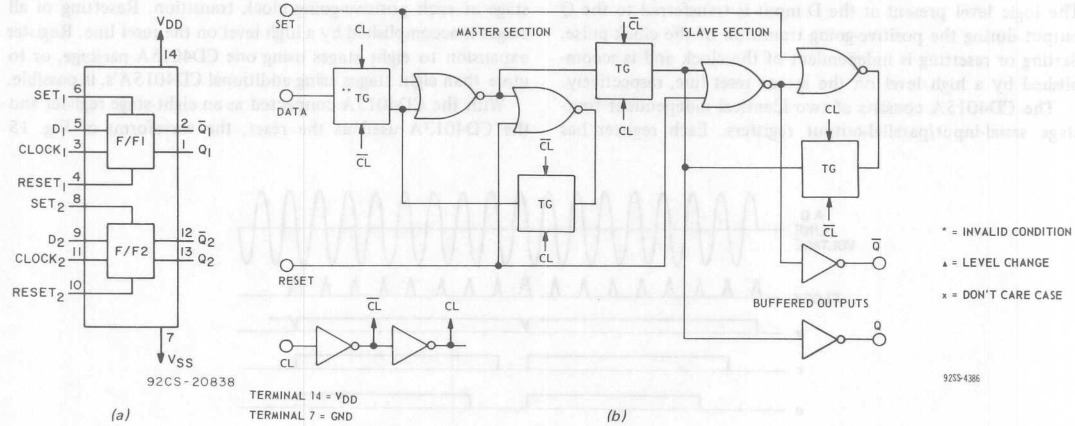


Fig. 13– Logic and block diagram of the CD4013A.

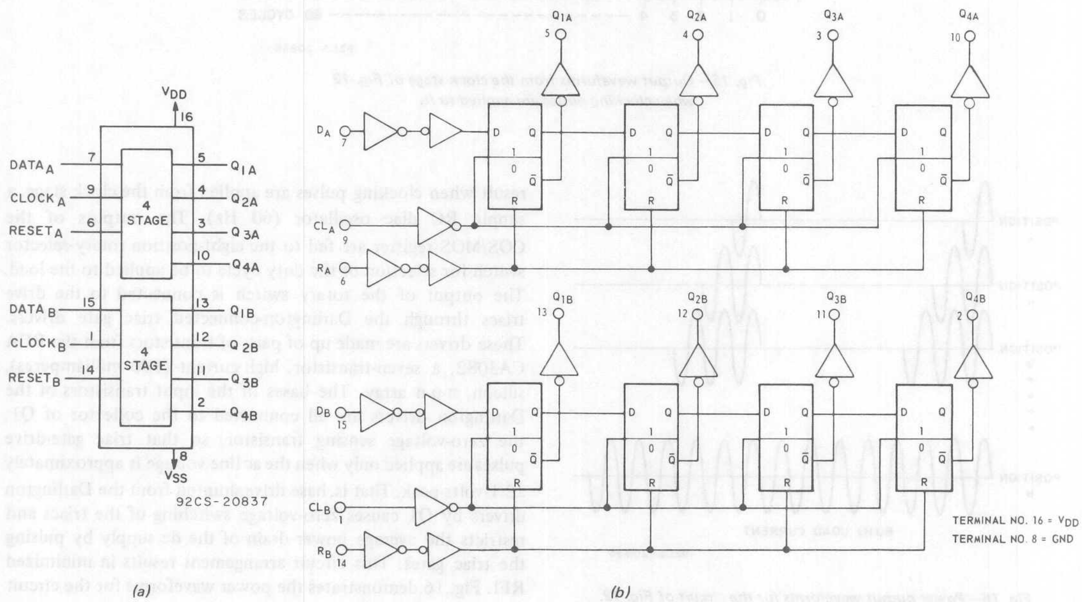


Fig. 14– Logic and block diagram of the CD4015A.

The RCA CD4013A consists of two identical independent data-type flip-flops. Each flip-flop has independent data, set, reset, and clock inputs and Q and $\overline{Q}$ outputs. These devices can be used for shift-register applications and, by connecting the Q output to the data input, for counter and toggle applications. The logic level present at the D input is transferred to the Q output during the positive-going transition of the clock pulse. Setting or resetting is independent of the clock and is accomplished by a high level on the set or reset line, respectively.

The CD4015A consists of two identical independent four-stage serial-input/parallel-output registers. Each register has independent clock and reset inputs as well as a single serial data input. Q outputs are available from each of the four stages on both registers. All register stages are D-type master-slave flip-flops. The logic level present at the data input is transferred into the first register stage and shifted over one stage at each positive-going clock transition. Resetting of all stages is accomplished by a high level on the reset line. Register expansion to eight stages using one CD4015A package, or to more than eight stages using additional CD4015A's, is possible.

With the CD4015A connected as an eight-stage register and the CD4013A used as the reset, the waveforms of Fig. 15 result when clocking pulses are applied from the clock stage, a simple RC diac oscillator (60 Hz). The outputs of the COS/MOS register are fed to the eight-position rotary-selector switch for selection of the duty cycle to be applied to the load. The output of the rotary switch is connected to the drive triacs through the Darlington-connected triac gate drivers. These drivers are made up of pairs of transistors from the RCA CA3082, a seven-transistor, high-current (100 milliamperes), silicon, n-p-n array. The bases of the input transistors of the Darlington drivers are all connected to the collector of Q1, the zero-voltage sensing transistor, so that triac gate-drive pulses are applied only when the ac line voltage is approximately ±2.1-volts peak. That is, base drive shunted from the Darlington drivers by Q1 causes zero-voltage switching of the triacs and restricts the average power drain of the dc supply by pulsing the triac gates. This circuit arrangement results in minimized RFI. Fig. 16 demonstrates the power waveforms for the circuit

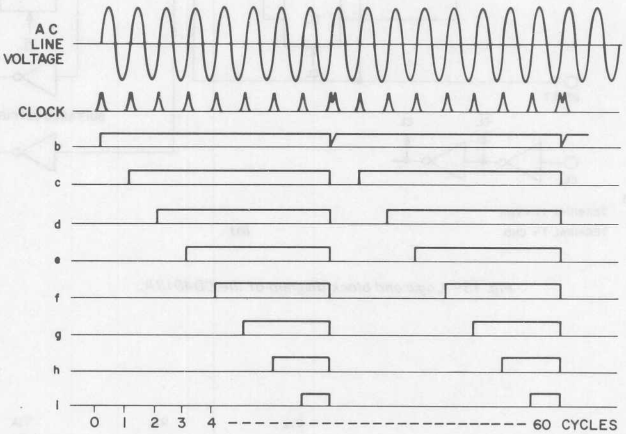


Fig. 15— Output waveforms from the clock stage of Fig. 12 when clocking pulses are applied to it.

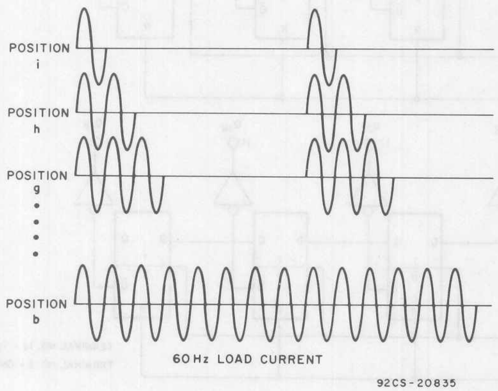


Fig. 16— Power-output waveforms for the circuit of Fig. 12.

of Fig. 12. Fig. 17 demonstrates the effect of the zero-voltage sensing transistor, Q1, and the relationship between the various COS/MOS outputs and the base drive and subsequent gate drive of the Darlington drivers. By using an additional selector switch, triac, and related gate circuitry (made up of spare transistors in the CA3082) a controllable convenience outlet can be provided. This outlet can be used for an electric fry-pan,

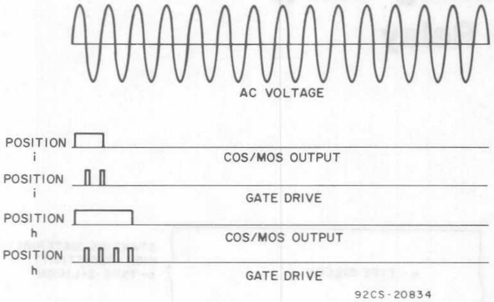


Fig. 17— Gating relationship waveforms for the circuit of Fig. 12.

coffee maker, waffle iron, toaster, etc., and can be controllable in the same manner as the top-burner elements.

An oven control is incorporated in the design by using an RCA CA3086, an array of five n-p-n transistors with one pair differentially-connected as a Schmitt trigger in closed-loop configuration. Again, the common dc supply of the system is used in addition to the zero-voltage sensing transistor, Q1. An additional Darlington pair available in the CA3082 is used for triac gating. As shown in Fig. 12, an NTC sensor, TH1, forms a voltage divider with the potentiometer, P1, the temperature-selector switch. The input transistor of the Schmitt trigger is a Darlington pair to provide sensitivity. Resistor R8 is chosen to allow for the desired amount of circuit hysteresis. When the sensor is cold and has a large resistance, the Darlington input is turned on and causes output transistor Q1 to turn off. The V_{CC} fed to the zero-voltage sensing transistor and respective gate drive switches the oven on. As the desired oven temperature is reached, the sensor resistance decreases and the voltage it controls drops below the switching threshold of the Schmitt trigger; this drop in voltage removes the gate drive to the oven. A PTC sensor could easily be used by inverting the sensor and potentiometer. Of course, with proper external switching of the oven elements and the incorporation of a fixed resistor to bias the Schmitt trigger to the high temperature of the self-cleaning mode, self-cleaning action can be accommodated by this system. Care must be taken, particularly with the location of the power triac for the oven, to afford the best possible ambient temperature conditions and heat sinking.

Conclusions

With the circuitry of Fig. 12, control of the temperature of the top burners is provided without the need for calibration of a sensor element, and the design is well suited for printed-circuit-board-module use. Extension of the circuit concept could lead to a future hybrid design incorporating custom chips. The nest of wiring which is now present in ranges is minimized by the use of the printed-circuit board. Zero-voltage switching of the power elements results in minimized RFI, while the single calibration between P1 and TH1 or an auxiliary calibration potentiometer is the only calibration necessary in the oven control. These concepts should lead to easier manufacture with limited in-line failures, because the printed-circuit-board modules could be tested before assembly into the range, and lower manufacturing costs because of the decreased amount of wiring. The history of solid-state dependability should also be reflected in the low amount of field failures.

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2. "Applications and Extended Operating Characteristics for the RCA-CA3059 IC Zero-Voltage Switch", by H. M. Kleinman and A. Sheng, RCA Application Note ICAN-6268.
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Power Switching Using Solid-State Relay

by T. C. McNulty

Solid-state relays make use of a semiconductor device for control of ac or dc power. Since, in most ac applications, the semiconductor element chosen for power control is the triac, this Note describes the triac as a power-switching element. Advantages and disadvantages of the active element over the electro-mechanical relay are discussed in general terms. Basic parameters, such as surge in-rush capability, transient-voltage ratings, suppression network, turn-off consideration and the different modes of triac gating are also discussed. AC power control is covered by various circuit designs for ON/OFF control, zero-voltage switching, and line-voltage isolation.

Power switching using electromechanical relays (EMR) is probably as old as the electrical industry is. The EMR is a controlled device having either an ON state or an OFF state capable of handling large amounts of power for a relatively low input power; it has widespread use in power and logic circuits. The relay comes in many forms (general purpose, telephone type, TO-5, reed, mercury wetted, etc.) and has various contact configurations. During the past few years, the EMR has been challenged by a new breed of relay which has no moving parts, is capable of handling large amounts of power for relatively low input power, and that comes in many package and circuit configurations. This new breed has been dubbed the "Solid-State Relay" or SSR, and uses transistors for dc power-control or triacs for ac power control. The SSR is particularly useful in areas in which increased reliability is required, and in which shock or mechanical fatigue impose severe limitations on the electromechanical relay. The major limitations to SSR use are economic factors, line isolation, immunity from line transients, and the need for multiple-pole arrangements.

TRIAC CONSTRUCTION

Thyristors (silicon controlled rectifiers and triacs) are semiconductor switches whose bistable state depends upon the regenerative feedback associated with a p-n-p-n structure. The SCR is a unidirectional device used primarily for dc and ac functions, whereas the triac is a bidirectional device used primarily for control of ac power.

The fabrication of a standard, glass-passivated triac requires the seven basic steps illustrated in Fig. 1 and delineated below.

1. The process begins with an n-type, high-resistivity, silicon wafer;
2. p layers are diffused deeply into both sides;
3. Silicon-dioxide diffusion masks are grown, and p+ regions are defined and diffused into the wafer;
4. A second oxide diffusion mask is grown, and n+ regions are defined and diffused into the wafer:
5. A silicon-dioxide etch mask is grown and defined. Grids and gate moats are etched into the wafer;

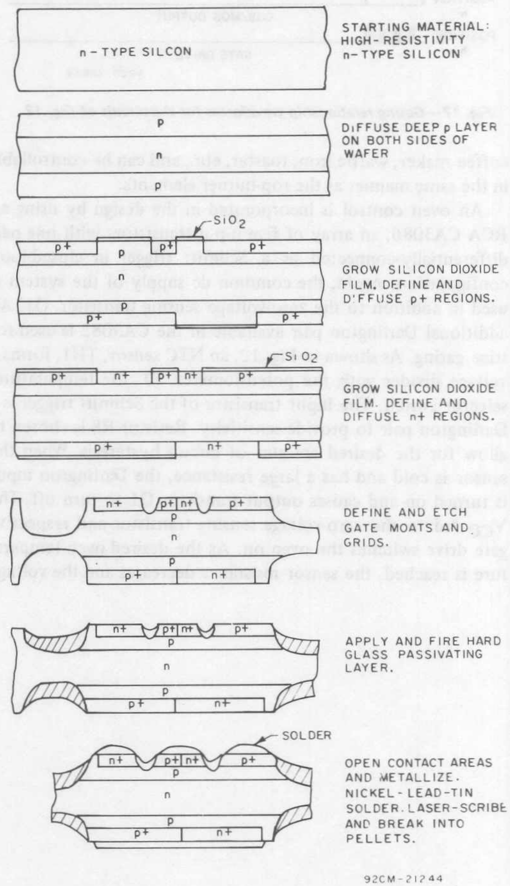


Fig.1 – The seven basic steps required in the fabrication of a standard, glass-passivated triac.

6. A hard glass-passivated layer is applied in the grids and gate moat;

7. Contact areas are opened on the wafer and nickel-lead-tin solder metallization is applied. The wafer is then laser-scribed and separated into pellets. Fig. 2 contains an isometric view of a completed triac and dimensions of three devices now available or in the design stage.

VOLTAGE AND TEMPERATURE RATINGS

The effects of voltage and temperature are important in thyristors because of the regenerative action of these devices, and because they

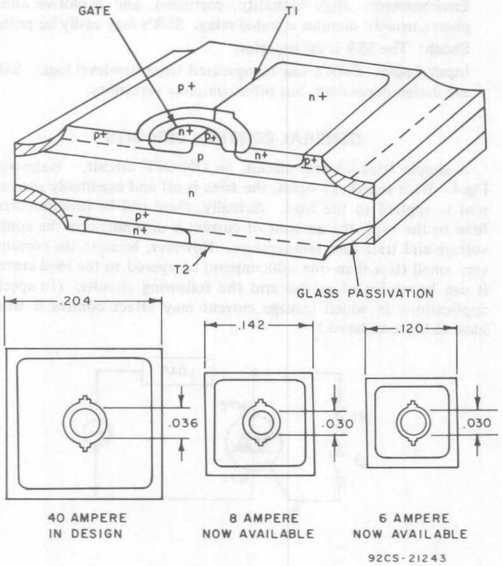


Fig.2 – An isometric view of a completed triac and dimensions of three devices now available or in the design stage.

are often required to support high voltages under high temperature conditions. The imposed voltages create a field at the junction interface, and the increased temperature releases additional surface ions. Should the field concentrate the additional surface charge and allow it to migrate into the gate region, non-gated turn-on may occur. Most manufacturers realize that the gate region must be terminated for high voltage/temperature operation, and a shunt resistance is built into the triac pellet during fabrication. This shunt reduces the immunity of the triac to non-gated turn-on. Additional reliability can be gained by operating the triac under less severe voltage/temperature conditions.

IN-RUSH CURRENTS

One of the features that has made thyristors the work-horses of the power semiconductor industry is their ability to absorb in-rush currents many times in excess of their steady-state ratings. This unique feature results from the regenerative action of the thyristor, an action which maintains the internal beta at a level such that, under in-rush conditions, the charge density is equally distributed over the entire triac pellet. The equal charge distribution assures the presentation of a low impedance to the in-rush current. Each manufacturer clearly rates device surge capability from single cycle to multiple cycles. Since this rating cannot be exceeded repeatedly, care should be exercised in the actual application to provide a sufficient safety margin between the published ratings and the actual circuit in-rush currents.

Another important parameter associated with a triac is its di/dt rating, a parameter most significant during turn-on. With the initiation of a gate signal, the active area closest to the gate region is, essentially, turned on, and, for a few microseconds, the instantaneous power dissipation is a function of the rate of rise of the on-state current. This power dissipation may cause localized heating and result in silicon-lattice destruction and triac degradation. The di/dt ratings are a function of triac geometry and pellet size, and ratings of 100 A/μs are easily achieved. In most circuit applications, stray or actual-load inductance is present, and for the condition of di/dt = E_{pk}/L, it is easily seen that a few microhenries of inductance are all that are required to limit circuit di/dt to within the maximum rating. When di/dt ratings are exceeded, it is usually because of the RC snubber network in parallel with the triac. In such networks, stray inductance is essentially zero, and the magnitude of discharge current is limited by the snubber resistance. The di/dt in the snubber is not affected by the inductance added to quell the di/dt caused by the stray or actual-load inductance; only careful selection of RC-snubber-network components will eliminate this second source of di/dt and minimize triac failures.

TRANSIENT VOLTAGES

It is well known that triacs are susceptible to non-gated turn-on and possible damage as a result of transient voltages. Transients are generally caused in a triac by the switching of inductive loads on adjacent lines or in proximity to the device. If the transient voltage generated exceeds the critical rate-of-rise of the off-state voltage (dv/dt) then a displacement current ($i = C \cdot dv/dt$) is generated which causes non-gated turn-on. Non-gated turn-on is not destructive if the energy transfer is within the maximum rating of the device; however, if the transient voltage does not exceed the off-state dv/dt rating, but does exceed the maximum voltage rating, then triac breakover occurs. Whether triac degradation occurs is dependent on whether the energy transfer is within the bulk silicon or the edge avalance.

Although the transient-voltage problem may seem critical, there are precautions that can be taken to minimize it. The use of RC snubbers in parallel with the triac can reduce the rate of imposed transients. This arrangement is most effective for fast rising, short-duration line disturbances. For critical applications, the use of a voltage-clipping device in addition to an RC snubber effectively suppresses both the rate of rise and magnitude of line-generated transients.

Another type of transient particularly prevalent in the area of inductive loads, and often overlooked, is the circuit-induced transient. Consider an inductive load in series with a triac and RC snubber network which also includes a switch for line-voltage interruption. With the triac in the off state, a leakage current flows which is a function of the characteristics of the load, the RC snubber network, and triac leakage. If the switch is momentarily opened when the triac is off, then a voltage transient ($E = L \cdot di/dt$) is generated which can exceed the voltage rating of the triac, cause non-gated turn-on and abrupt energy transfer; and may result in damage to the triac. Again, the proper selection of RC-network components and voltage-clipping device will suppress the circuit-induced transient to a level compatible with the voltage rating of the triac.

COMMUTATING dv/dt

The term "turn-off time" is not associated with triacs since triacs are bidirectional, and reverse voltage is nothing more than a forward voltage to one-half of the triac chip. A new term, "critical-rate-of-rise-of-commutation-voltage", is used with triacs. The term describes the ability of the triac to turn off as the current passes through zero, or commutates. One must remember that the triac is a current-dependent device: current is injected into the gate to turn the device on, and current must be removed or allowed to pass through zero for turn-off regardless of what the source-voltage polarity is. Commutating dv/dt is less critical with resistive loads and most important with inductive loads. Consider an inductive load in which the load current lags the source voltage by a phase angle θ. As pointed out,

triac commutation occurs at zero current, whereas the source voltage has some magnitude E. As the load current crosses the zero point, a small reverse current is established as a result of the charge in the n-type region. This charge, plus a displacement current ($i = C \cdot dv/dt$) resulting from the reapplied source voltage, can cause the triac to turn on in the absence of a proper gate signal. A minimum commutating dv/dt at rated current and at a specific operating case temperature should be defined in all triac applications; the circuit designer can use these specifications to choose an RC snubber network that will limit the reapplied dv/dt to within ratings. Loss of triac control as a result of commutating dv/dt does not degrade the characteristics of the triac. Proper RC snubber network selections for worst-case conditions of load power factor, current, and voltage are easily made by use of the charts shown in Fig.3.

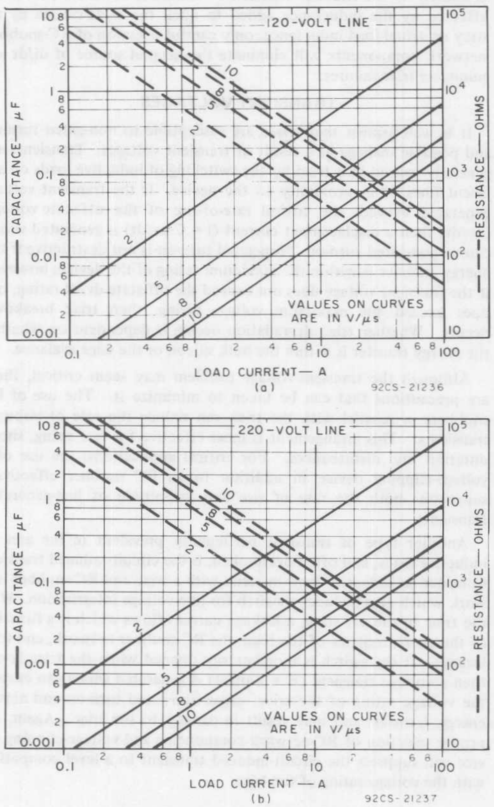


Fig.3 – (a) Snubber components for 200-volt peak on 120-volt line; (b) Snubber components for 400-volt peak on 220-volt line.

ADVANTAGES OF SSR's

Before the advantages of SSR's are discussed, the types available should be reviewed.

Two types of SSR are available: all solid-state and hybrids. The solid-state class employs solid-state devices for both logic and triac gating. Hybrids generally use a reed relay for triac gating for ac power control and so combine the electromechanical with solid state. In either class, the triac is used as the solid-state element for ac power control. A comparison of SSR's with electromechanical relays is given below.

Life: An EMR physically makes and breaks load current, and the relay contacts deteriorate with life.

SSR's: They have no moving parts, and may be designed to make and break at zero current. Regardless of the design, the triac always breaks at zero current.

Contact Bounce: Inherent with an EMR – zero for SSR's.

RFI: Inherent with EMR's – dependent on SSR design.

AFI: ("audio-frequency" interference). Terrible with EMR's, particularly when many relays are clacking about. Not noticeable with SSR's.

Environment: High humidity, corrosion, and explosive atmospheres usually dictates a sealed relay. SSR's may easily be potted.

Shock: The SSR is far superior.

Input Logic: EMR's can be operated from low-level logic. SSR's are design dependent, but offer complete versatility.

GENERAL CONTROL CIRCUITS

A simple triac control circuit, an ON/OFF circuit, is shown in Fig.4. With switch S1 open, the triac is off and essentially zero current is applied to the load. Actually, there will be leakage-current flow to the load; the amount of current is dependent on the applied voltage and triac case temperature. However, because the current is very small (less than one milliampere) compared to the load current, it can be neglected in this and the following circuits. (In specific applications in which leakage current may affect control it would have to be considered.)

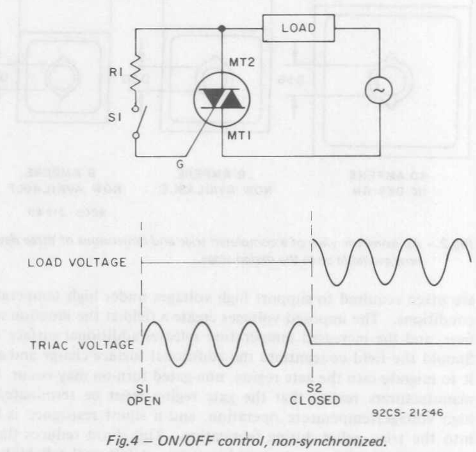


Fig.4 – ON/OFF control, non-synchronized.

To apply power to the load in Fig.4, switch S1 is closed to provide gate drive to the triac. Bias-resistor R1 is of the order of 68 to 100 ohms and provides the initial gate drive during every half cycle of applied voltage. The power consumption of R1 is very low (1/4 to 1/2 watt), because, when the triac is in the ON state, R1 is in parallel with the ON-state voltage of approximately 1.5 volts. This method of triac triggering, called anode firing, is an effective way of triggering because it uses the source voltage as a source of gate-current drive. Maximum gate current is available for triac turn-on at peak line voltage until the device goes to the low-impedance state. In this state the current in R1 is reduced by the forward voltage drop. In effect, bias resistor R1 is utilized only during the initial turn-on of the triac, or for approximately two microseconds. In a typical application, switch S1 would be replaced by a relay, and power control would be transferred by means of low-level-current relay contacts.

For control applications which require that variable power be delivered to a load, an inexpensive RC phase-control circuit is best. Fig.5 shows the basic triac-diac control circuit with the triac connected in series with the load. During the beginning of each half cycle

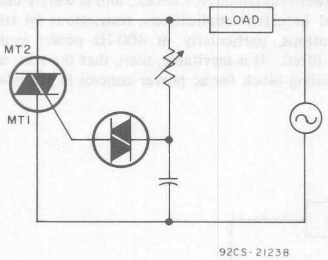


Fig.5 – RC phase control, variable power.

the triac is in the OFF state; as a result, the entire line voltage is impressed across it. Because the triac is in parallel with the potentiometer and capacitor, the voltage across the triac drives the current through the potentiometer and charges the capacitor. When the capacitor voltage reaches the breakover voltage of the diac, V_{BO}, the capacitor discharges through the triac gate and turns it on. The line voltage is then transferred from the triac to the load for the remainder of that half cycle. This sequence is repeated for every half cycle of either polarity. If the potentiometer resistance is reduced, the capacitor charges more rapidly, the V_{BO} of the diac is reached earlier in the cycle, and the power applied to the load is increased. If the potentiometer resistance is increased, triggering occurs later and load power is reduced. The main disadvantage of this circuit is that it produces RFI.

Although the basic light-control circuit operates with the component arrangement shown in Fig.5, additional components and sections are usually added to reduce hysteresis effects, extend the effective range of power control, and suppress radio-frequency interference.

TEMPERATURE-CONTROL CIRCUITS

A zero-voltage-switch, Fig.6, synchronized for line-pulse generation, in combination with a triac, is particularly well suited for temperature-control applications. The zero-voltage-switch/triac circuit may be used with an ON/OFF-type control or as a proportional control depending on the degree of regulation required. A simple, inexpensive, ON/OFF temperature controller is shown in Fig.7; a review of the functional block diagram of the zero-voltage-switch, Fig.6, will help in understanding the circuit. For every zero-voltage crossing, a zero crossing pulse is generated and directed to the triac gating circuit. If there is a demand for heat, the differential amplifier is in the open state, the triac gating circuit is open, and the triac is turned on at every zero-voltage crossing. When the demand for heat is satisfied, the differential amplifier is in the closed state; this inhibits the triac gating circuit and removes any further gate drive to the triac. Therefore, the key to the operation of this circuit is in the state of the differential amplifier. One side of the differential amplifier is biased to a reference voltage V_R, and the other side is biased to a voltage V_S which is dependent on a variable potentiometer setting and sensing resistor. As a result, whenever the bias voltage V_S exceeds the reference voltage V_R, the gating circuit is open and the triac is turned on for each zero-voltage crossing. The characteristics of an ON/OFF controller are well known; i.e., there are significant thermal overshoots and undershoots which result in a differential temperature above and below the reference temperature. The magnitude of the differential temperature is dependent on the mass of the heater and the time constant of the sensing element.

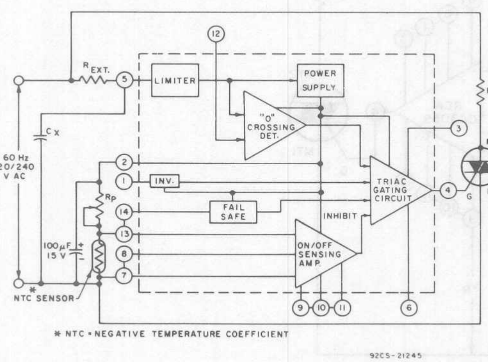


Fig.6 – Functional block diagram of the integrated-circuit zero-voltage-switch, CA3059.

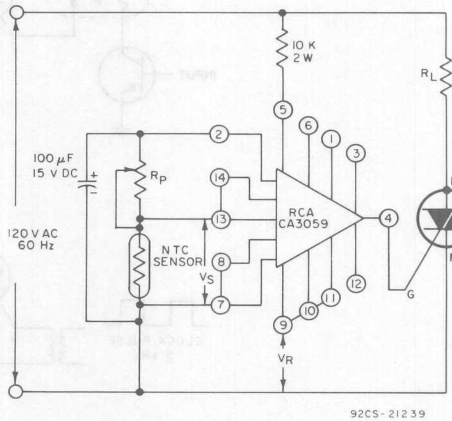


Fig.7 – CA3059 ON/OFF temperature controller.

For precise temperature control, the technique of proportional control with synchronous switching is introduced. The proportional control differs from the ON/OFF control in that it allows a specified percentage of power (duty cycle) to be supplied to the load with a finite off time that, in turn, allows the heating element to "catch up" as a result of thermal lag. In effect, this scheme provides "anticipator control." Again, the key to circuit operation is in the state of the differential amplifier.

AC LINE ISOLATION

The design engineer often must provide dc-to-ac isolation. Complete isolation can be achieved by reed relays, pulse transformers, and light-activated devices. Selection of any one of these three approaches depends on the dc logic design and component economics. Fig.8 (a) shows a reed relay and transistor drive circuit which is effective in triac gating, although it does have moving parts. Fig.8 (b) uses a pulse transformer for isolation, and requires a form of clock pulse that can be transferred to the triac gate. In some applications, clock pulses may already be available; therefore the pulse-transformer approach is economical. This approach requires more components than that of Fig.8 (a), but it has no moving parts. The last approach,

and, at present, probably the most expensive one, uses a light-activated device, such as the GaAs infrared (IR) emitter, to initiate triac gating. The light-activated device is coupled to a photosensitive transistor which, when turned on, provides inhibit logic for additional integrated circuits or, as in Fig. 8 (c), for a zero-voltage-switch application.

CONCLUSION

This paper has illuminated some of those areas most misunderstood or considered as problem areas in the application of triacs. The designer who thoroughly understands the characteristics and limitations, but most of all the advantages, of triacs, will have at his disposal a device that he can use to design power controllers that operate satisfactorily not only in normal applications, but also in severe physical and electrical environments. The triac has already proven to be a true power-semiconductor device, and is widely used in both commercial and industrial applications; restrictions on triac use in military applications, particularly in 400-Hz power systems, are gradually being lifted. It is inevitable, then, that the triac will evolve as the basic building block for ac power control in power-controller systems.

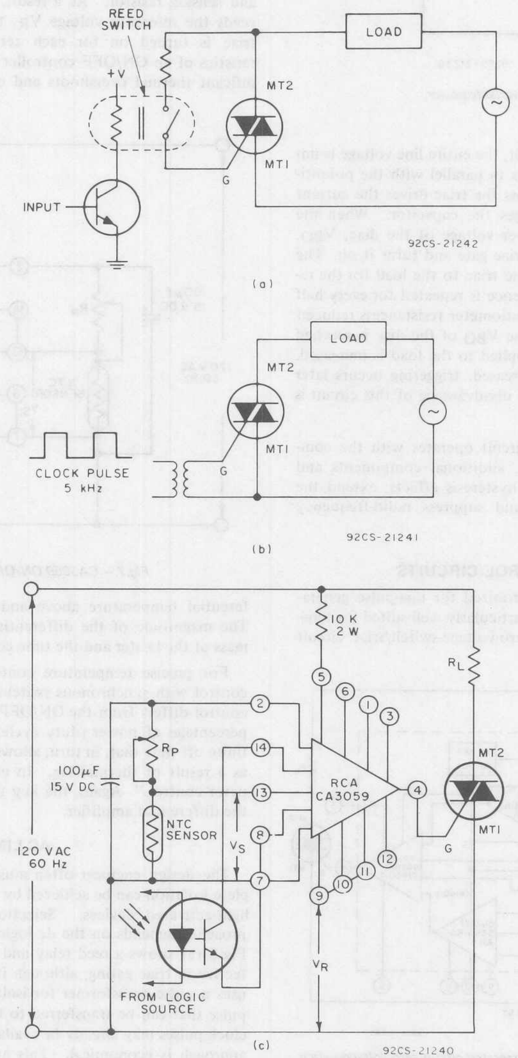


Fig.8 – (a) Isolation with reed relay; (b) isolation with pulse transformer; (c) isolation with light-activated devices.

Features and Applications of RCA Integrated-Circuit Zero-Voltage Switches (CA3058, CA3059, and CA3079)

by A. C. N. Sheng, G. J. Granieri, and J. Yellin

RCA-CA3058, CA3059 and CA3079 zero-voltage switches are monolithic integrated circuits designed primarily for use as trigger circuits for thyristors in many highly diverse ac power-control and power-switching applications. These integrated-circuit switches operate from an ac input voltage of 24, 120, 208 to 230, or 277 volts at 50, 60, or 400 Hz.

The CA3059 and CA3079 are supplied in a 14-terminal dual-in-line plastic package. The CA3058 is supplied in a 14-terminal dual-in-line ceramic package. The electrical and physical characteristics of each type are detailed in RCA Data Bulletin File No. 490.

RCA zero-voltage switches (ZVS) are particularly well suited for use as thyristor trigger circuits. These switches trigger the thyristors at zero-voltage points in the supply-voltage cycle. Consequently, transient load-current surges and radio-frequency interference (RFI) are substantially reduced. In addition, use of the zero-voltage switches also reduces the rate of change of on-state current (di/dt) in the thyristor being triggered, an important consideration in the operation of thyristors. These switches can be adapted for use in a variety of control functions by use of an internal differential comparator to detect the difference between two externally developed voltages. In addition, the availability of numerous terminal connections to internal circuit points greatly increases circuit flexibility and further expands the types of ac power-control applications to which these integrated circuits may be adapted. The excellent versatility of the zero-voltage switches is demonstrated by the fact that these circuits have been used to provide transient-free temperature control in self-cleaning ovens, to control gun-muzzle temperature in low-temperature environments, to provide sequential switching of heating elements in warm-air furnaces, to switch traffic signal lights at street intersections, and to effect other widely different ac power-control functions.

FUNCTIONAL DESCRIPTION

RCA zero-voltage switches are multistage circuits that employ a diode limiter, a zero-crossing (threshold) detector, an on-off sensing amplifier (differential comparator), and a Darlington output driver (thyristor gating circuit) to provide the basic switching action. The dc operating voltages for these stages is provided by an internal power supply that has sufficient current capability to drive external circuit elements, such as transistors and other integrated circuits. An important feature of the zero-voltage switches is that the output trigger pulses can be applied directly to the gate of a triac or a silicon controlled rectifier (SCR). The CA3058 and CA3059 also feature an interlock (protection) circuit that inhibits the application of these pulses to the thyristor in the event that the external sensor should be inadvertently opened or shorted. An external inhibit connection (terminal No. 1) is also available so that an external signal can be used to inhibit the output drive. This feature is not included in the CA3079; otherwise, the three integrated-circuit zero-voltage switches are electrically identical.

Over-all Circuit Operation

Fig. 1 shows the functional interrelation of the zero-voltage switch, the external sensor, the thyristor being triggered, and the load elements in an on-off type of ac power-control system. As shown, each of the zero-voltage switches incorporates four functional blocks as follows:

(1) Limiter-Power Supply – Permits operation directly from an ac line.

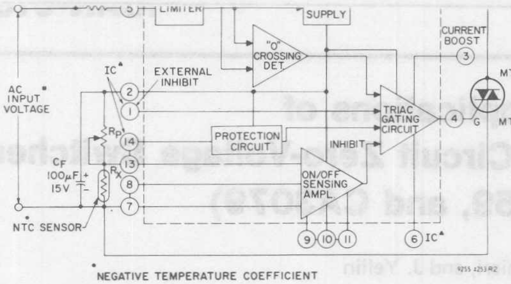
(2) Differential On/Off Sensing Amplifier – Tests the condition of external sensors or command signals. Hysteresis or proportional-control capability may easily be implemented in this section.

(3) Zero-Crossing Detector – Synchronizes the output pulses of the circuit at the time when the ac cycle is at a zero-voltage point and thereby eliminates radio-frequency inteference (RFI) when used with resistive loads.

(4) Triac Gating Circuit – Provides high-current pulses to the gate of the power-controlling thyristor.

In addition, the CA3058 and CA3059 provide the following important auxiliary functions (shown in Fig. 1):

(1) A built-in protection circuit that may be actuated to remove drive from the triac if the sensor opens or shorts.



AC Input Voltage (50/60 or 400 Hz) V AC	Input Series Resistor (R_S) k Ω	Dissipation Rating for R_S W
24	2	0.5
120	10	2
208/230	20	4
277	25	5

Fig. 1 – Functional block diagrams of the zero-voltage switches CA3058, CA3059, and CA3079.

overriding the action of the zero-crossing detector. This override is accomplished by connecting terminal 12 to terminal 7. Gate current to the thyristor is continuous when terminal 13 is positive with respect to terminal 9.

Fig. 2 shows the detailed circuit diagram for the integrated-circuit zero-voltage switches. (The diagrams shown in Figs. 1 and 2 are representative of all three RCA zero-voltage switches, i.e., the CA3058, CA3059, and CA3079; the shaded areas indicate the circuitry that is not included in the CA3079.)

The limiter stage of the zero-voltage switch clips the incoming ac line voltage to approximately ±8 volts. This signal is then applied to the zero-voltage-crossing detector, which generates an output pulse each time the line voltage passes through zero. The limiter output is also applied to a rectifying diode and an external capacitor, C_F, that comprise the dc power supply. The power supply provides approximately 6 volts as the V_{CC} supply to the other stages of the zero-voltage switch. The on-off sensing amplifier is basically a differential comparator. The thyristor gating circuit contains a driver for direct triac triggering. The gating circuit is enabled when all the inputs are at a "high" voltage, i.e., the line voltage must be approximately zero volts, the sensing-amplifier output must be "high," the external voltage to terminal 1 must be a logical "0", and, for the CA3058 and CA3059, the output of the fail-safe circuit must be "high." Under these conditions, the thyristor (triac or SCR) is triggered when the line voltage is essentially zero volts.

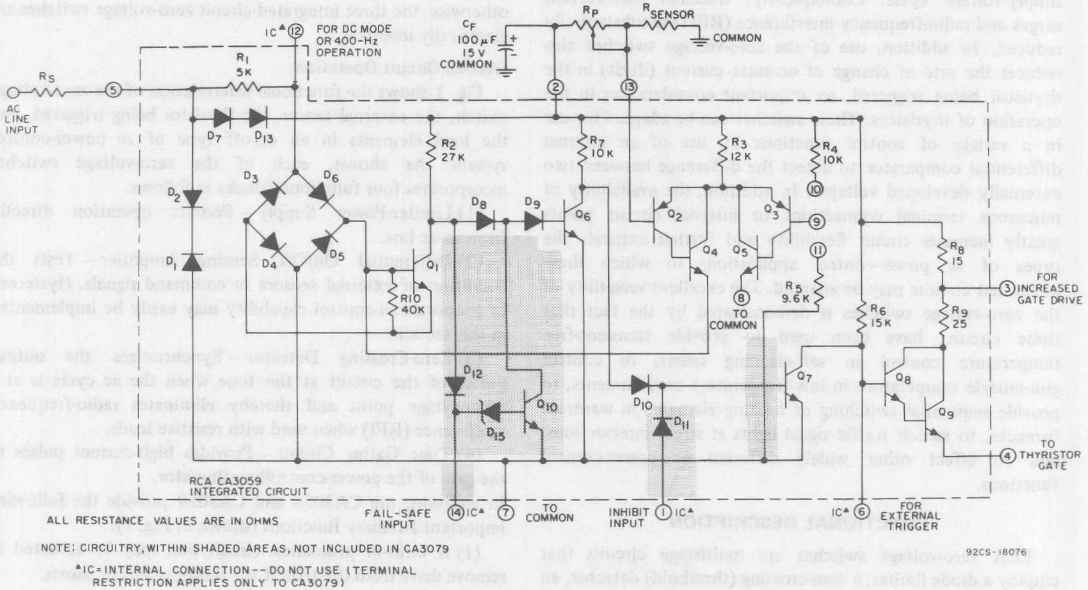


Fig. 2 – Schematic diagram of zero-voltage switches CA3058, CA3059, and CA3079.

Thyristor Triggering Circuits

The diodes D_1 and D_2 in Fig. 2 form a symmetrical clamp that limits the voltages on the chip to ±8 volts; the diodes D_7 and D_{13} form a half-wave rectifier that develops a positive voltage on the external storage capacitor, C_F.

The output pulses used to trigger the power-switching thyristor are actually developed by the zero-crossing detector and the thyristor gating circuit. The zero-crossing detector consists of diodes D_3 through D_6, transistor Q_1, and the associated resistors shown in Fig. 2. Transistors Q_1 and Q_6 through Q_9 and the associated resistors comprise the thyristor gating circuit and output driver. These circuits generate the output pulses when the ac input is at a zero-voltage point so that RFI is virtually eliminated when the zero-voltage switch and thyristor are used with resistive loads.

The operation of the zero-crossing detector and thyristor gating circuit can be explained more easily if the on state (i.e., the operating state in which current is being delivered to the thyristor gate through terminal 4) is considered as the operating condition of the gating circuit. Other circuit elements in the zero-voltage switch inhibit the gating circuit unless certain conditions are met, as explained later.

In the on state of the thyristor gating circuit, transistors Q_8 and Q_9 are conducting, transistor Q_7 is off, and transistor Q_6 is on. Any action that turns on transistor Q_7 removes the drive from transistor Q_8 and thereby turns off the thyristor. Transistor Q_7 may be turned on directly by application of a minimum of ±1.2 volts at 10 microamperes to the external-inhibit input, terminal 1. (If a voltage of more than 1.5 volts is available, an external resistance must be added in series with terminal 1 to limit the current to 1 milliampere.) Diode D_{10} isolates the base of transistor Q_7 from other signals when an external-inhibit signal is applied so that this signal is the highest priority command for normal operation. (Although grounding of terminal 6 creates a higher-priority inhibit function, this level is not compatible with normal DTL or TTL logic levels.) Transistor Q_7 may also be activated by turning off transistor Q_6 to allow current flow from the power supply through resistor R_7 and diode D_{10} into the base of Q_7. Transistor Q_6 is normally maintained in conduction by current that flows into its base through resistor R_2 and diodes D_8 and D_9 when transistor Q_1 is off.

Transistor Q_1 is a portion of the zero-crossing detector. When the voltage at terminal 5 is greater than +3 volts, current can flow through resistor R_1, diode D_6, the base-to-emitter junction of transistor Q_1, and diode D_4 to terminal 7 to turn on Q_1. This action inhibits the delivery of a gate-drive output signal at terminal 4. For negative voltages at terminal 5 that have magnitudes greater than 3 volts, the current flows through diode D_5, the emitter-to-base junction of transistor Q_1, diode D_3, and resistor R_1, and again turns on transistor Q_1. Transistor Q_1 is off only when the voltage at terminal 5 is less than the threshold voltage of approximately ±2 volts. When the integrated-circuit zero-voltage switch is connected as shown in Fig. 1, therefore, the output is a narrow pulse which is approximately centered about the zero-voltage time in the cycle, as shown in Fig. 3. In some applications, however,

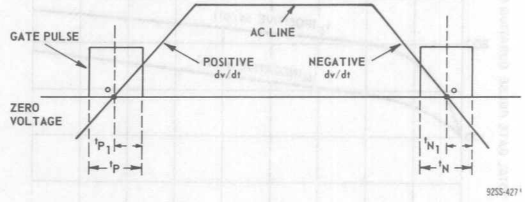


Fig. 3 – Waveform showing output-pulse duration of the zero-voltage switch.

particularly those that use either slightly inductive or low-power loads, the thyristor load current does not reach the latching-current value* by the end of this pulse. An external capacitor C_X connected between terminal 5 and 7, as shown in Fig. 4, can be used to delay the pulse to accommodate such loads. The amount of pulse stretching and delay is shown in Figs. 5(a) and 5(b).

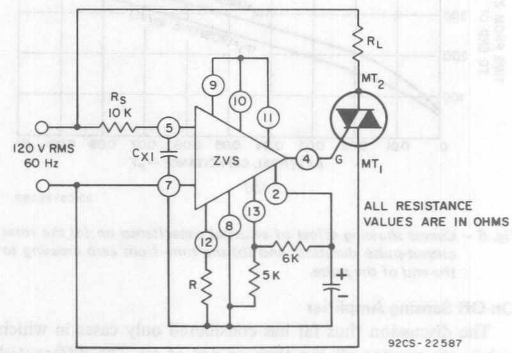


Fig. 4 – Use of a capacitor between terminals 5 and 7 to delay the output pulse of the zero-voltage switch.

Continuous gate current can be obtained if terminal 12 is connected to terminal 7 to disable the zero-crossing detector. In this mode, transistor Q_1 is always off. This mode of operation is useful when comparator operation is desired or when inductive loads must be switched. (If the capacitance in the load circuit is low, most RFI is eliminated.) Care must be taken to avoid overloading of the internal power supply in this mode. A sensitive-gate thyristor should be used, and a resistor should be placed between terminal 4 and the gate of the thyristor to limit the current, as pointed out later under **Special Application Considerations.**

Fig. 6 indicates the timing relationship between the line voltage and the zero-voltage- switch output pulses. At 60 Hz, the pulse is typically 100 microseconds wide; at 400 Hz, the pulse width is typically 12 microseconds. In the basic circuit shown, when the dc logic signal is "high", the output is disabled; when it is "low", the gate pulses are enabled.

* The latching current is the minimum current required to sustain conduction immediately after the thyristor is switched from the off to the on state and the gate signal is removed.

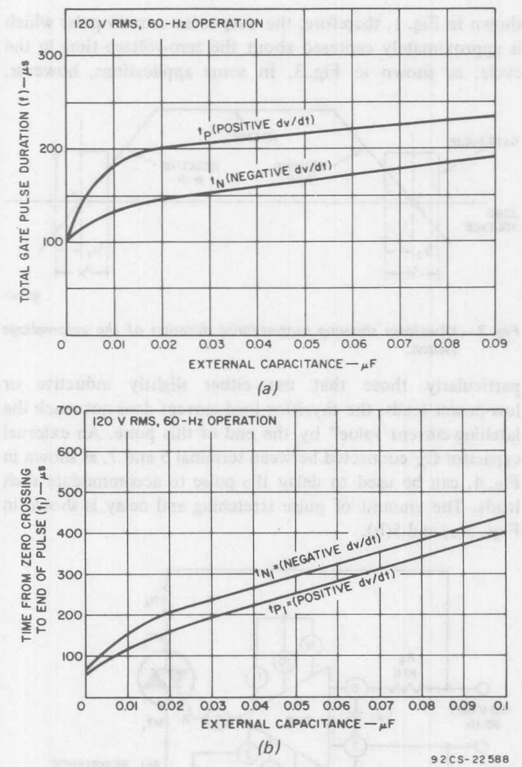


Fig. 5 – Curves showing effect of external capacitance on (a) the total output-pulse duration, and (b) the time from zero crossing to the end of the pulse.

On-Off Sensing Amplifier

The discussion thus far has considered only cases in which pulses are present all the time or not at all. The differential sense amplifier consisting of transistors Q_2, Q_3, Q_4, and Q_5 (shown in Fig. 2) makes the zero-voltage switch a flexible power-control circuit. The transistor pairs Q_2-Q_4 and Q_3-Q_5 form a high-beta composite p-n-p transistors in which the emitters of transistors Q_4 and Q_5 act as the collectors of the composite devices. These two composite transistors are connected as a differential amplifier with resistor R_3 acting as a constant-current source. The relative current flow in the two "collectors" is a function of the difference in voltage between the bases of transistors Q_2 and Q_3. Therefore, when terminal 13 is more positive than terminal 9, little or no current flows in the "collector" of the transistor pair Q_2-Q_4. When terminal 13 is negative with respect to terminal 9, most of the current flows through that path, and none in terminal 8. When current flows in the transistor pair Q_2-Q_4, the path is from the supply through R_3, through the transistor pair Q_2-Q_4, through the base-emitter junction of transistor Q_1, and finally through the diode D_4 to terminal 7. Therefore, when V_{13} is equal to or more negative than V_9, transistor Q_1 is on, and the output is inhibited.

In the circuit shown in Fig. 1, the voltage at terminal 9 is derived from the supply by connection of terminals 10 and 11 to form a precision voltage divider. This divider forms one side of a transducer bridge, and the potentiometer R_P and the negative-temperature-coefficient (NTC) sensor form the other side. At low temperatures, the high resistance of the sensor causes terminal 13 to be positive with respect to terminal 9 so that the thyristor fires on every half-cycle, and power is applied to the load. As the temperature increases, the sensor resistance decreases until a balance is reached, and V_{13} approaches V_9. At this point, the transistor pair Q_2-Q_4 turns on and inhibits any further pulses. The controlled temperature is adjusted by variation of the value of the potentiometer R_P. For cooling service, either the positions of R_P and the sensor may be reversed or terminals 9 and 13 may be interchanged.

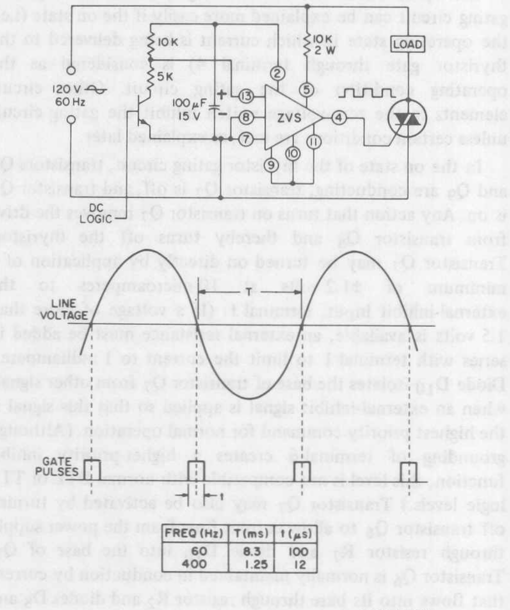


Fig. 6 – Timing relationship between the output pulses of the RCA zero-voltage switch and the ac line voltage.

The low bias current of the sensing amplifier permits operation with sensor impedances of up to 0.1 megohm at balance without introduction of substantial error (i.e., greater than 5 per cent). The error may be reduced if the internal bridge elements, resistors R_4 and R_5, are not used, but are replaced with resistances which equal the sensor impedance. The minimum value of sensor impedance is restricted by the current drain on the internal power supply. Operation of the zero-voltage switch with low-impedance sensors is discussed later under **Special Application Considerations**. The voltage applied to terminal 13 must be greater than 1.8 volts at all times to assure proper operation.

Protection Circuit

A special feature of the CA3058 and CA3059 zero-voltage switches is the inclusion of an interlock type of circuit. This circuit removes power from the load by interrupting the thyristor gate drive if the sensor either shorts or opens. However, use of this circuit places certain constraints upon the user. Specifically, effective protection-circuit operation is dependent upon the following conditions:

(1) The circuit configuration of Fig. 1 is used, with an internal supply, no external load on the supply, and terminal 14 connected to terminal 13.

(2) The value of potentiometer R_p and of the sensor resistance must be between 2000 ohms and 0.1 megohm.

(3) The ratio of sensor resistance and R_p must be greater than 0.33 and less than 3.0 for all normal conditions. (If either of these ratios is not met with an unmodified sensor, a series resistor or a shunt resistor must be added to avoid undesired activation of the circuit.)

The protective feature may be applied to other systems when operation of the circuit is understood. The protection circuit consists of diodes D_{12} and D_{15} and transistor Q_{10}. Diode D_{12} activates the protection circuit if the sensor shown in Fig. 1 shorts or its resistance drops too low in value, as follows: Transistor Q_6 is on during an output pulse so that the junction of diodes D_8 and D_{12} is 3 diode drops (approximately 2 volts) above terminal 7. As long as V_{14} is more positive or only 0.15 volt negative with respect to that point, diode D_{12} does not conduct, and the circuit operates normally. If the voltage at terminal 14 drops to 1 volt, the anode of diode D_8 can have a potential of only 1.6 to 1.7 volts, and current does not flow through diodes D_8 and D_9 and transistor Q_6. The thyristor then turns off.

The actual threshold is approximately 1.2 volts at room temperature, but decreases 4 millivolts per degree C at higher temperatures. As the sensor resistance increases, the voltage at terminal 14 rises toward the supply voltage. At a voltage of approximately 6 volts, the zener diode D_{15} breaks down and turns on transistor Q_{10}, which then turns off transistor Q_6 and the thyristor. If the supply voltage is not at least 0.2 volt more positive than the breakdown voltage of diode D_{15}, activation of the protection circuit is not possible. For this reason, loading the internal supply may cause this circuit to malfunction, as may selection of the wrong external supply voltage. Fig. 7 shows a guide for the proper operation of the protection circuit when an external supply is used with a typical integrated-circuit zero-voltage switch.

SPECIAL APPLICATION CONSIDERATIONS

As pointed out previously, the RCA integrated-circuit zero-voltage switches (CA3058, CA3059, and CA3079) are exceptionally versatile units that can be adapted for use in a wide-variety of power-control applications. Full advantage of this versatility can be realized, however, only if the user has a basic understanding of several fundamental considerations that apply to certain types of applications of the zero-voltage switches.

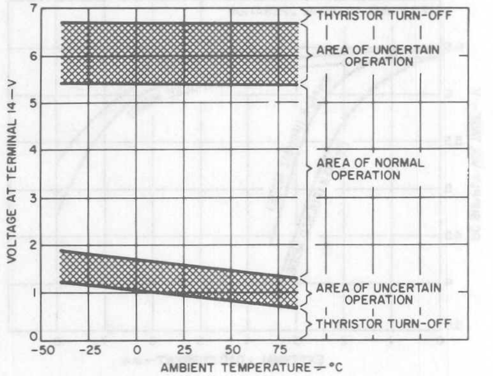


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Fig. 7 – Operating regions for built-in protection circuits of a typical zero-voltage switch.

Operating-Power Options

Power to the zero-voltage switch may be derived directly from the ac line, as shown in Fig. 1, or from an external dc power supply connected between terminals 2 and 7, as shown in Fig. 8. When the zero-voltage switch is operated directly from the ac line, a dropping resistor R_S of 5,000 to 10,000 ohms must be connected in series with terminal 5 to limit the current in the switch circuit. The optimum value for this resistor is a function of the average current drawn from the internal dc power supply, either by external circuit elements or by the thyristor trigger circuits, as shown in Fig. 9. The chart shown in Fig. 1 indicates the value and dissipation rating of the resistor R_S for ac line voltages of 24, 120, 208 to 230, and 277 volts.

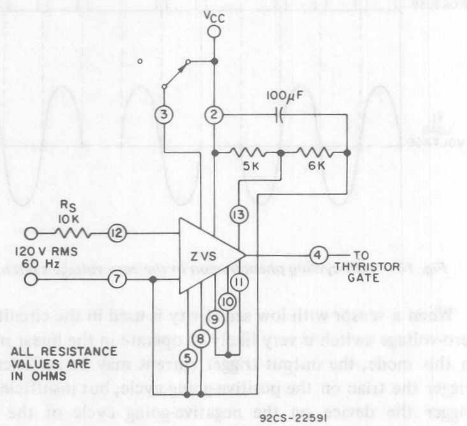

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Fig. 8 – Operation of the zero-voltage switch from an external dc power supply connected between terminals 2 and 7.

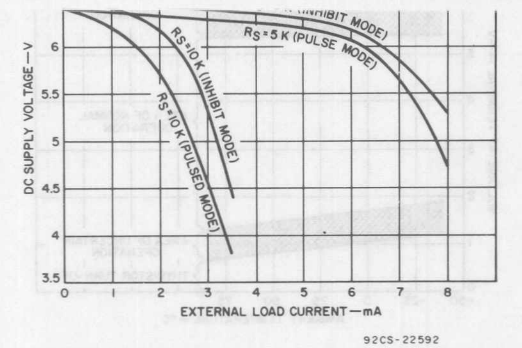


Fig. 9 – DC supply voltage as a function of external load current for several values of dropping resistance R_S.

Half-Cycling Effect

The method by which the zero-voltage switch senses the zero crossing of the ac power results in a half-cycling phenomenon at the control point. Fig. 10 illustrates this phenomenon. The zero-voltage switch senses the zero-voltage crossing every half-cycle, and an output, for example pulse No. 4, is produced to indicate the zero crossing. During the remaining 8.3 milliseconds, however, the differential amplifier in the zero-voltage switch may change state and inhibit any further output pulses. The uncertainty region of the differential amplifier, therefore, prevents pulse No. 5 from triggering the triac during the negative excursion of the ac line voltage.

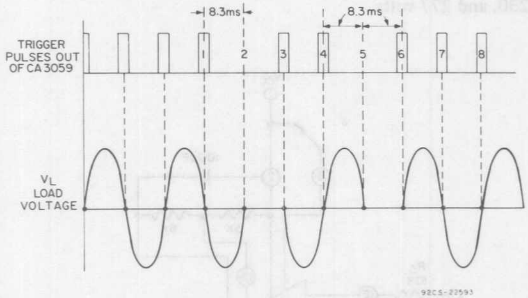
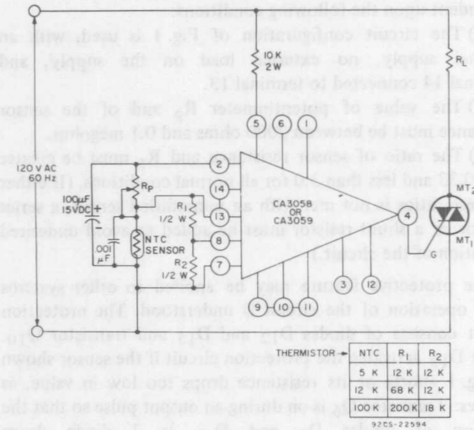


Fig. 10 – Half-cycling phenomenon in the zero-voltage switch.

When a sensor with low sensitivity is used in the circuit, the zero-voltage switch is very likely to operate in the linear mode. In this mode, the output trigger current may be sufficient to trigger the triac on the positive-going cycle, but insufficient to trigger the device on the negative-going cycle of the triac supply voltage. This effect introduces a half-cycling phenomenon, i.e., the triac is turned on during the positive half-cycle and turned off during the negative half-cycle.

around the differential amplifier. Fig. 11 illustrates this technique. The tabular data in the figure lists the recommended values of resistors R_1 and R_2 for different sensor impedances at the control point.



NTC	R_1	R_2
5 K	12 K	12 K
12 K	68 K	12 K
100 K	200 K	18 K

Fig. 11 – CA3058 or CA3059 on-off controller with hysteresis.

If a significant amount (greater than ±10%) of controlled hysteresis is required, then the circuit shown in Fig. 12 may be employed. In this configuration, external transistor Q_1 can be used to provide an auxiliary timed-delay function.

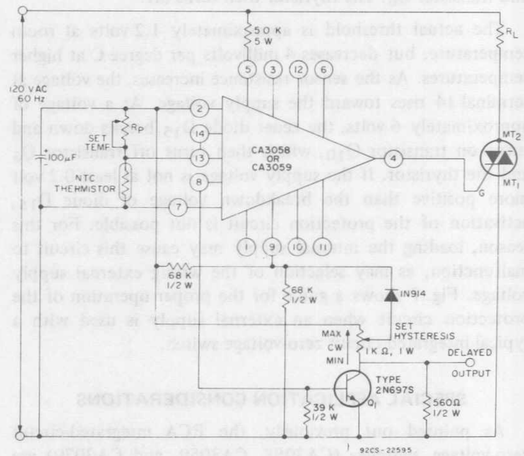


Fig. 12 – CA3058 or CA3059 on-off controller with controlled hysteresis.

For applications that require complete elimination of half-cycling without the addition of hysteresis, the circuit shown in Fig. 13 may be employed. This circuit uses a

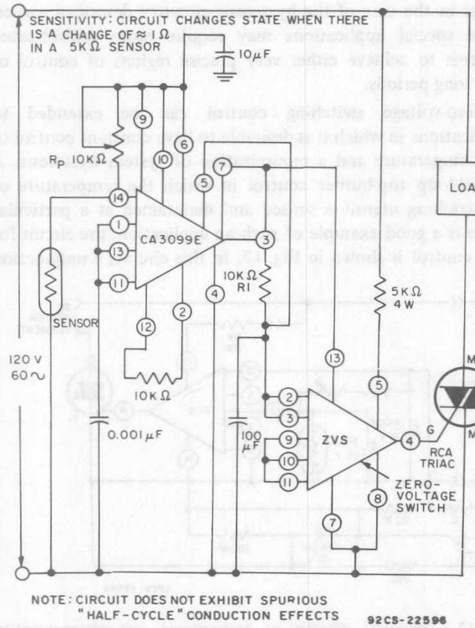


Fig. 13 – Sensitive temperature control.

CA3099E integrated-circuit programmable comparator with a zero-voltage switch. A block diagram of CA3099E is shown in Fig. 14. Because the CA3099E contains an integral flip-flop, its output will be in either a "0" or "1" state. Consequently the zero-voltage switch cannot operate in the linear mode, and spurious half-cycling operation is prevented. When the signal-input voltage at terminal 14 of the CA3099E is equal to or less than the "low" reference voltage (LR), current flows from the power supply through resistor R_1, and a logic "0" is applied to terminal 13 of the zero-voltage switch. This condition turns off the triac. The triac remains off until the signal-input voltage rises to or exceeds the "high" reference voltage (HR), thereby effecting a change in the state of the flip-flop so that a logic "1" is applied to terminal 13 of the zero-voltage switch, and triggers the triac on.

"Proportional Control" Systems

The on-off nature of the control shown in Fig. 1 causes some overshoot that leads to a definite steady-state error. The addition of hysteresis adds further to this error factor. However, the connections shown in Fig. 15(a) can be used to add proportional control to the system. In this circuit, the sense amplifier is connected as a free-running multivibrator. At balance, the voltage at terminal 13 is much less than the voltage at terminal 9. The output will be inhibited at all times until the voltage at terminal 13 rises to the design differential voltage between terminals 13 and 9; then proportional control resumes. The voltage at terminal 13 is as shown in Fig. 15(b). When this voltage is more positive than the threshold, power is

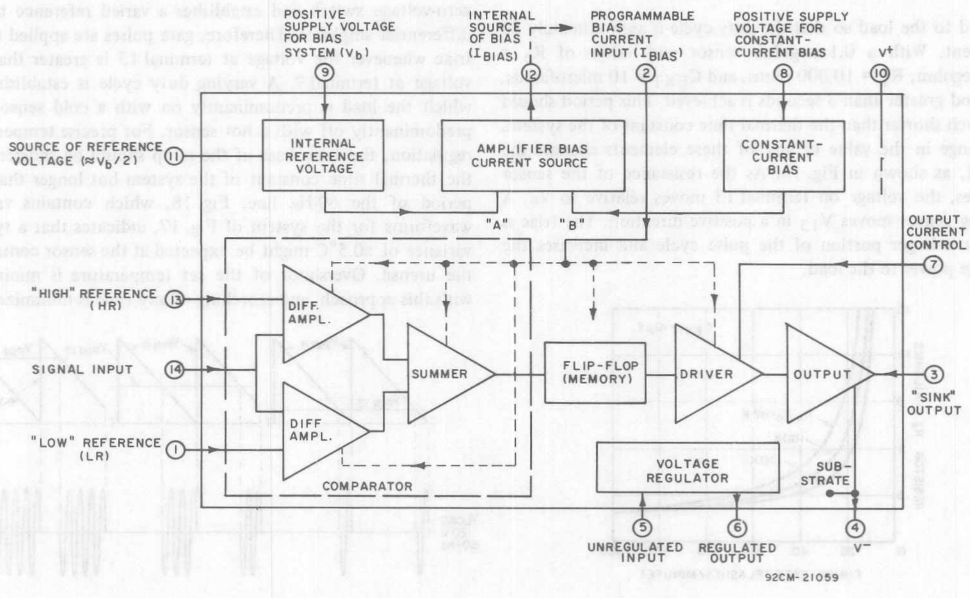


Fig. 14 – Block diagram of CA3099E integrated-circuit programmable comparator.

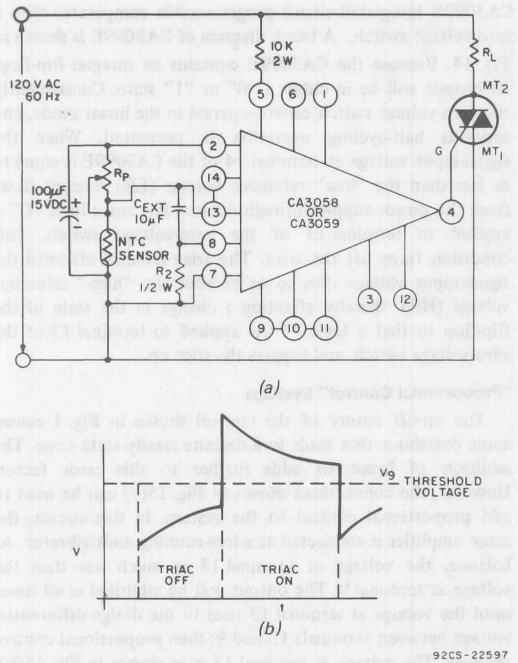


Fig. 15 – Use of the CA3058 or CA3059 in a typical heating control with proportional control: (a) schematic diagram, and (b) waveform of voltage at terminal 13.

applied to the load so that the duty cycle is approximately 50 per cent. With a 0.1 megohm sensor and values of R_P 0.1 megohm, R_2 = 10,000 ohms, and C_{EXT} = 10 microfarads, a period greater than 3 seconds is achieved. This period should be much shorter than the thermal time constant of the system. A change in the value of any of these elements changes the period, as shown in Fig. 16. As the resistance of the sensor changes, the voltage on terminal 13 moves relative to V_9. A cooling sensor moves V_{13} in a positive direction. The triac is on for a larger portion of the pulse cycle and increases the average power to the load.

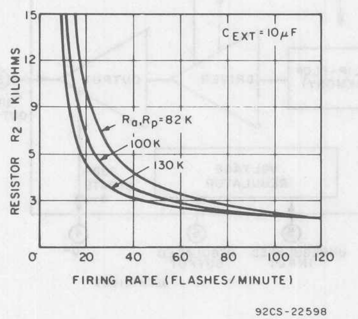


Fig. 16 – Effect of variations in time-constant elements on period.

As in the case of the hysteresis circuitry described earlier, some special applications may require more sophisticated systems to achieve either very precise regions of control or very long periods.

Zero-voltage switching control can be extended to applications in which it is desirable to have constant control of the temperature and a minimization of system hysteresis. A closed-loop top-burner control in which the temperature of the cooking utensil is sensed and maintained at a particular value is a good example of such an application; the circuit for this control is shown in Fig. 17. In this circuit, a unijunction

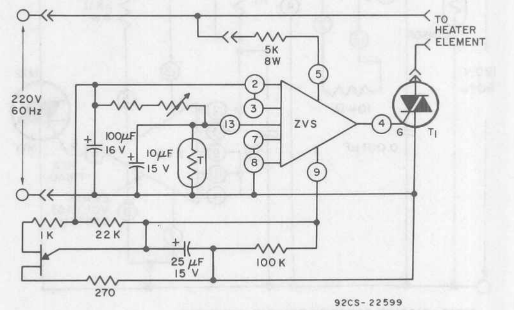


Fig. 17 – Schematic diagram of proportional zero-voltage-switching control.

oscillator is outboarded from the basic control by means of the internal power supply of the zero-voltage switch. The output of this ramp generator is applied to terminal 9 of the zero-voltage switch and establishes a varied reference to the differential amplifier. Therefore, gate pulses are applied to the triac whenever the voltage at terminal 13 is greater than the voltage at terminal 9. A varying duty cycle is established in which the load is predominantly on with a cold sensor and predominantly off with a hot sensor. For precise temperature regulation, the time base of the ramp should be shorter than the thermal time constant of the system but longer than the period of the 60-Hz line. Fig. 18, which contains various waveforms for the system of Fig. 17, indicates that a typical variance of ±0.5°C might be expected at the sensor contact to the utensil. Overshoot of the set temperature is minimized with this approach, and scorching of any type is minimized.

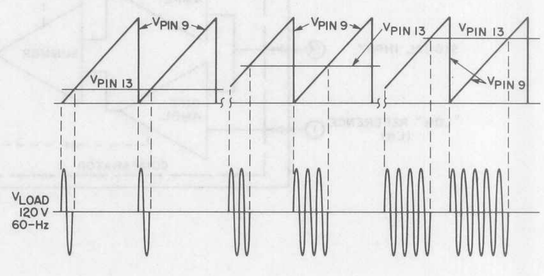


Fig. 18 – Waveforms for the circuit of Fig. 17.

Effect of Thyristor Load Characteristics

The zero-voltage switch is designed primarily to gate a thyristor that switches a resistive load. Because the output pulse supplied by the switch is of short duration, the latching current of the triac becomes a significant factor in determining whether other types of loads can be switched. (The latching-current value determines whether the triac will remain in conduction after the gate pulse is removed.) Provisions are included in the zero-voltage switch to accommodate inductive loads and low-power loads. For example, for loads that are less than approximately 4 amperes rms or that are slightly inductive, it is possible to retard the output pulse with respect to the zero-voltage crossing by insertion of the capacitor C_X from terminal 5 to terminal 7. The insertion of capacitor C_X permits switching of triac loads that have a slight inductive component and that are greater than approximately 200 watts (for operation from an ac line voltage of 120 volts rms). However, for loads less than 200 watts (for example, 70 watts), it is recommended that the user employ the T2300B* sensitive-gate triac with the zero-voltage switch because of the low latching-current requirement of this triac.

For loads that have a low power factor, such as a solenoid valve, the user may operate the zero-voltage switch in the dc mode. In this mode, terminal 12 is connected to terminal 7, and the zero-crossing detector is inhibited. Whether a "high" or "low" voltage is produced at terminal 4 is then dependent only upon the state of the differential comparator within the integrated-circuit zero-voltage switch, and not upon the zero crossing of the incoming line voltage. Of course, in this mode of operation, the zero-voltage switch no longer operates as a zero-voltage switch. However, for many applications that involve the switching of low-current inductive loads, the amount of RFI generated can frequently be tolerated.

For switching of high-current inductive loads, which must be turned on at zero line current, the triggering technique employed in the dual-output over-under temperature controller and the transient-free switch controller described subsequently in this Note is recommended.

Switching of Inductive Loads

For proper driving of a thyristor in full-cycle operation, gate drive must be applied soon after the voltage across the device reverses. When resistive loads are used, this reversal occurs as the line voltage reverses. With loads of other power factors, however, it occurs as the current through the load becomes zero and reverses.

There are several methods for switching an inductive load at the proper time. If the power factor of the load is high (i.e., if the load is only slightly inductive), the pulse may be delayed by addition of a suitable capacitor between terminals 5 and 7, as described previously. For highly inductive loads, however, this method is not suitable, and different techniques must be used.

If gate current is continuous, the triac automatically commutates because drive is always present when the voltage reverses. This mode is established by connection of terminals 7 and 12. The zero-crossing detector is then disabled so that current is supplied to the triac gate whenever called for by the sensing amplifier. Although the RFI-eliminating function of the zero-voltage switch is inhibited when the zero-crossing detector is disabled, there is no problem if the load is highly inductive because the current in the load cannot change abruptly.

Circuits that use a sensitive-gate triac to shift the firing point of the power triac by approximately 90 degrees have been designed. If the primary load is inductive, this phase shift corresponds to firing at zero current in the load. However, changes in the power factor of the load or tolerances of components will cause errors in this firing time.

The circuit shown in Fig. 19 uses a CA3086 integrated-circuit transistor array to detect the absence of load current by sensing the voltage across the triac. The internal zero-crossing detector is disabled by connection of terminal 12 to terminal 7, and control of the output is made through the external inhibit input, terminal 1. The circuit permits an output only when the voltage at point A exceeds two V_{BE} drops, or 1.3 volts. When A is positive, transistors Q_3 and Q_4 conduct and reduce the voltage at terminal 1 below the inhibit state. When A is negative, transistors Q_1 and Q_2 conduct. When the voltage at point A is less than ±1.3 volts, neither of the transistor pairs conducts; terminal 1 is then pulled positive by the current in resistor R_3, and the output in inhibited.

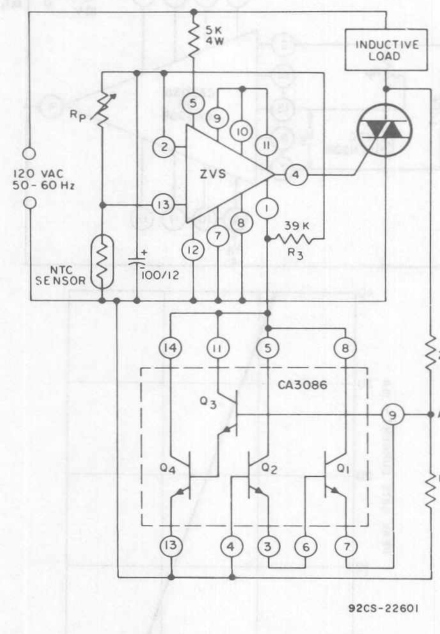


Fig. 19 – Use of the CA3058 or CA3059 together with CA3086 for switching inductive loads.

The circuit shown in Fig. 19 forms a pulse of gate current and can supply high peak drive to power traics with low average current drain on the internal supply. The gate pulse will always last just long enough to latch the thyristor so that

* Formerly RCA 40526

disabled and initial turn-on occurs at random.

The gate pulse forms because the voltage at point A when the thyristor is on is less than 1.3 volts: therefore, the output of the zero-voltage switch is inhibited, as described above. The resistor divider R_1 and R_2 should be selected to assure this condition. When the triac is on, the voltage at point A is approximately one-third of the instantaneous on-state voltage (v_T) of the thyristor. For most RCA thyristors, v_T (max) is less than 2 volts, and the divider shown is a conservative one. When the load current passes through zero, the triac commutates and turns off. Because the circuit is still being driven by the line voltage, the current in the load attempts to reverse, and voltage increases rapidly across the "turned-off" triac. When this voltage exceeds 4 volts, one portion of the CA3086 conducts and removes the inhibit signal to permit application of gate drive. Turning the triac on causes the

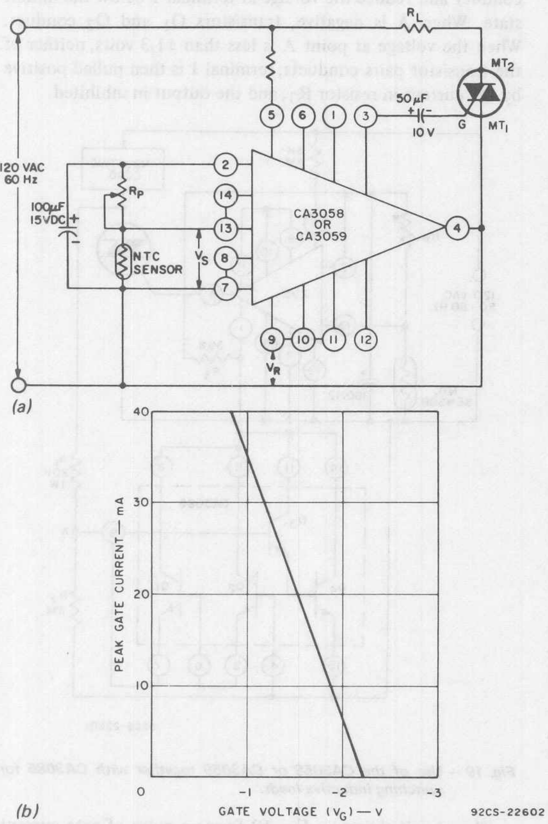


Fig. 20 – Use of the CA3058 or CA3059 to provide negative gate pulses: (a) schematic diagram; (b) peak gate current (at terminal 3) as a function of gate voltage.

Provision of Negative Gate Current

Triacs trigger with optimum sensitivity when the polarity of the gate voltage and the voltage at the main terminal 2 are similar (I^+ and III^- modes). Sensitivity is degraded when the polarities are opposite (I^- and III^+ modes). Although RCA triacs are designed and specified to have the same sensitivity in both I^- and III^+ modes, some other types have very poor sensitivity in the III^+ condition. Because the zero-voltage switch supplies positive gate pulses, it may not directly drive some higher-current triacs of these other types.

The circuit shown in Fig. 20(a) uses the negative-going voltage at terminal 3 of the zero-voltage switch to supply a negative gate pulse through a capacitor. The curve in Fig. 20(b) shows the approximate peak gate current as a function of gate voltage V_G. Pulse width is approximately 80 microseconds.

Operation with Low-Impedance Sensors

Although the zero-voltage switch can operate satisfactorily with a wide range of sensors, sensitivity is reduced when sensors with impedances greater than 20,000 ohms are used. Typical sensitivity is one per cent for a 5000-ohm sensor and increases to three per cent for a 0.1-megohm sensor.

Low-impedance sensors present a different problem. The sensor bridge is connected across the internal power supply and causes a current drain. A 5000-ohm sensor with its associated 5000-ohm series resistor draws less than 1 milliampere. On the other hand, a 300-ohm sensor draws a current of 8 to 10 milliampers from the power supply.

Fig. 21 shows the 600-ohm load line of a 300-ohm sensor on a redrawn power-supply regulation curve for the zero-voltage switch. When a 10,000-ohm series resistor is used, the voltage across the circuit is less than 3 volts and both sensitivity and output current are significantly reduced. When a 5000-ohm series resistor is used, the supply voltage is nearly 5 volts, and operation is approximately normal. For more consistent operation, however, a 4000-ohm series resistor is recommended.

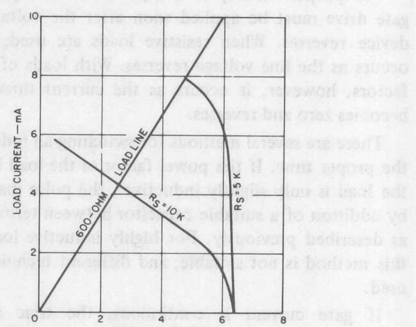


Fig. 21 – Power-supply regulation of the CA3058 or CA3059 with a 300-ohm sensor (600-ohm load) for two values of series resistor.

Although positive-temperature-coefficient (PTC) sensors rated at 5 kilohms are available, the existing sensors in ovens are usually of a much lower value. The circuit shown in Fig. 22 is offered to accommodate these inexpensive metal-wound

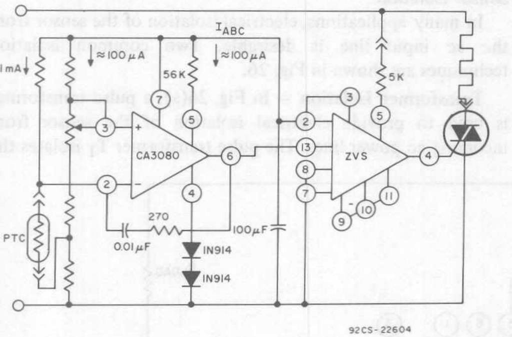


Fig. 22 – Schematic diagram of circuit for use with low-resistance sensor.

sensors. A schematic diagram of the RCA CA3080 integrated-circuit operational transconductance amplifier used in Fig. 22, is shown in Fig. 23. With an amplifier bias current, I_{ABC}, of 100 microamperes, a forward transconductance of 2 milliohms is achieved in this configuration. The CA3080 switches when the voltage at terminal 2 exceeds the voltage at terminal 3. This action allows the sink current, I_s, to flow from terminal 13 of the zero-voltage switch (the input impedance to terminal 13 of the zero-voltage switch is approximately 50 kilohms); gate pulses are no longer applied to the triac because Q_2 of the zero-voltage switch is on. Hence, if the PTC sensor is cold, i.e., in the low resistance state, the load is energized. When the temperature of the PTC sensor increases to the desired temperature, the sensor enters the high resistance state, the voltage on terminal 2 becomes greater than that on terminal 3, and the triac switches the load off. Further cycling depends on the voltage across the sensor. Hence, very low values of sensor and potentiometer resistance can be used in conjunction with the zero-voltage switch power supply without causing adverse loading effects and impairing system performance.

Interfacing Techniques

Fig. 24 shows a system diagram that illustrates the role of the zero-voltage switch and thyristor as an interface between the logic circuitry and the load. There are several basic

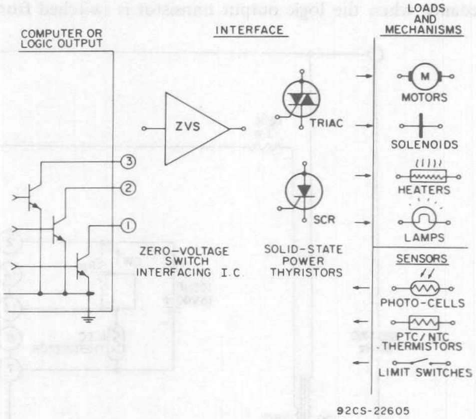


Fig. 24 – The zero-voltage switch and thyristor as an interface.

interfacing techniques. Fig. 25(a) shows the **direct input** technique. When the logic output transistor is switched from the on state (saturated) to the off state, the load will be turned on at the next zero-voltage crossing by means of the interfacing zero-voltage switch and the triac. When the logic output transistor is switched back to the on state, zero-crossing pulses from the zero-voltage switch to the triac

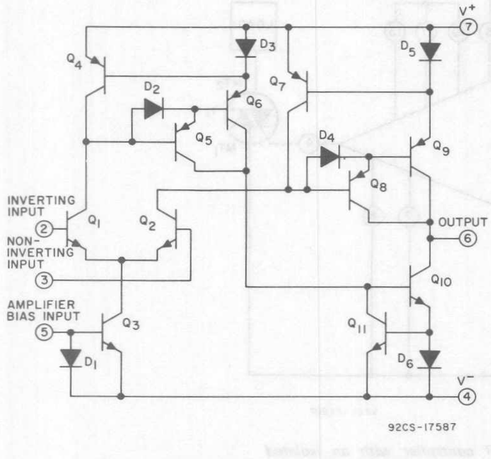


Fig. 23 – Schematic diagram of the CA3080.

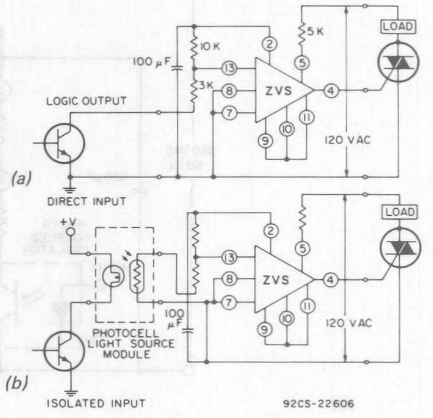


Fig. 25 – Basic interfacing techniques: (a) direct input; (b) isolated input.

gate will immediately cease. Therefore, the load will be turned off when the triac commutates off as the sine-wave load current goes through zero. In this manner, both the turn-on and turn-off conditions for the load are controlled.

When electrical isolation between the logic circuit and the load is necessary, the **isolated-input** technique shown in Fig. 25(b) is used. In the technique shown, optical coupling is used to achieve the necessary isolation. The logic output transistor switches the light-source portion of the isolator. The light-sensor portion changes from a high impedance to a low impedance when the logic output transistor is switched from off to on. The light sensor is connected to the differential amplifier input of the zero-voltage switch, which senses the change of impedance at a threshold level and switches the load on as in Fig. 25(a).

Sensor Isolation

In many applications, electrical isolation of the sensor from the ac input line is desirable. Two common isolation techniques are shown in Fig. 26.

Transformer Isolation – In Fig. 26(a), a pulse transformer is used to provide electrical isolation of the sensor from incoming ac power lines. The pulse transformer T_1 isolates the

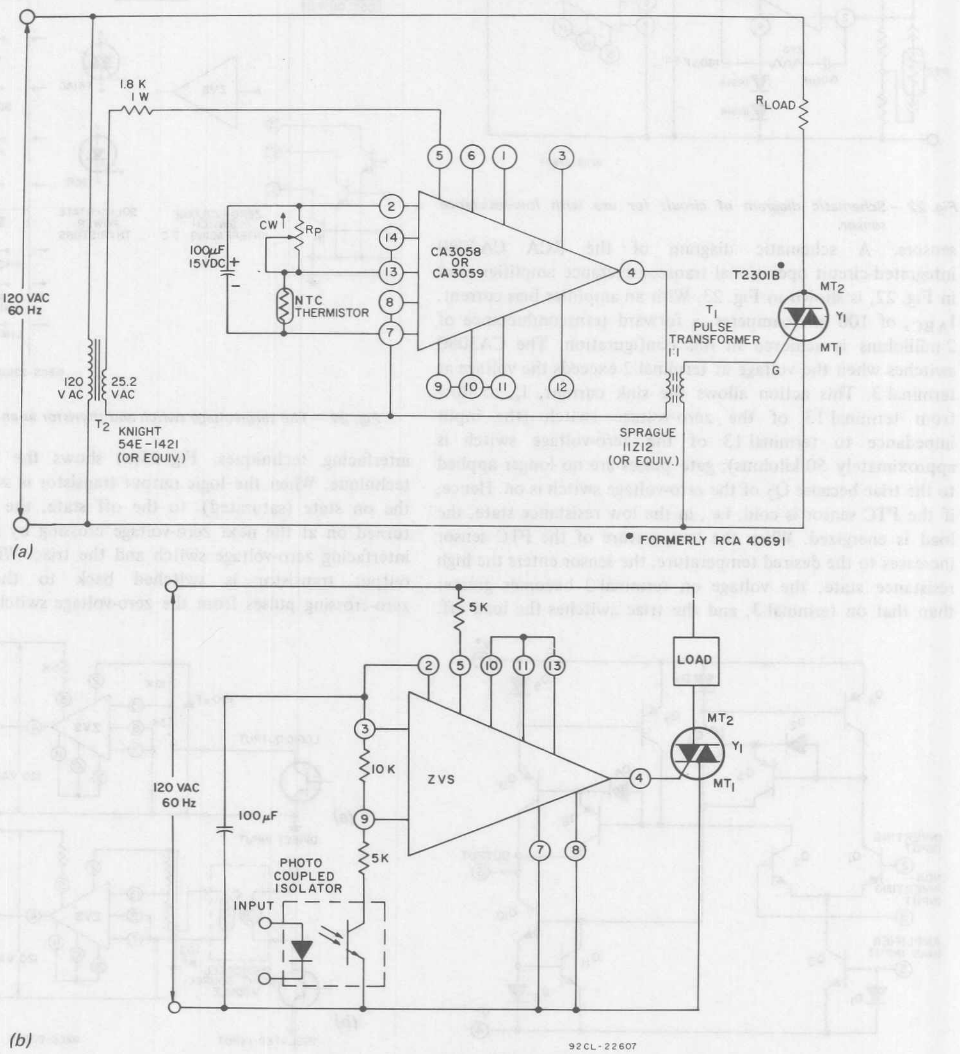


Fig. 26 – Zero-voltage switch (a) on-off controller with an isolated sensor, (b) on-off controller with photocoupler.

sensor from terminal No. 1 of the triac Y_1, and transformer T_2 isolates the CA3058 or CA3059 from the power lines. Capacitor C_1 shifts the phase of the output pulse at terminal No. 4 in order to retard the gate pulse delivered to triac Y_1 to compensate for the small phase-shift introduced by transformer T_1.

Photocoupler Isolation – In Fig. 26(b), a photocoupler provides electrical isolation of the sensor logic from the incoming ac power lines. When a logic "1" is applied at the input of the photocoupler, the triac controlling the load will be turned on whenever the line voltage passes through zero. When a logic "0" is applied to the photocoupler, the triac will turn off and remain off until a logic "1" appears at the input of the photocoupler.

TEMPERATURE CONTROLLERS

Fig. 27 shows a triac used in an on-off temperature-controller configuration. The triac is turned on at zero voltage whenever the voltage V_s exceeds the reference

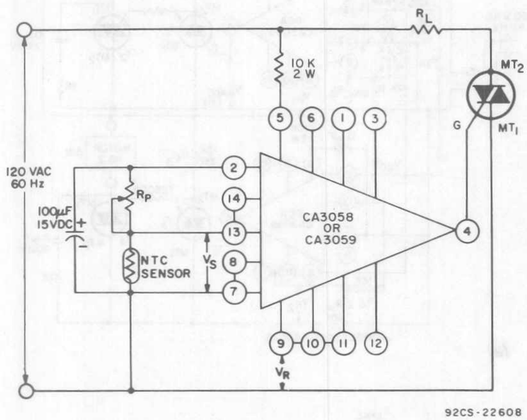


Fig. 27 – CA3058 or CA3059 on-off temperature controller.

voltage V_r. The transfer characteristic of this system, shown in Fig. 28(a), indicates significant thermal overshoots and undershoots, a well-known characteristic of such a system. The differential or hysteresis of this system, however, can be further increased, if desired, by the addition of positive feedback.

For precise temperature-control applications, the proportional-control technique with synchronous switching is employed. The transfer curve for this type of controller is shown in Fig. 28(b). In this case, the duty cycle of the power supplied to the load is varied with the demand for heat required and the thermal time constant (inertia) of the system. For example, when the temperature setting is increased in an on-off type of controller, full power (100 per cent duty cycle) is supplied to the system. This effect results in significant temperature excursions because there is no anticipatory circuit to reduce the power gradually before the actual set temperature is achieved. However, in a proportional control technique, less power is supplied to the load (reduced duty cycle) as the error signal is reduced (sensed temperature approaches the set temperature).

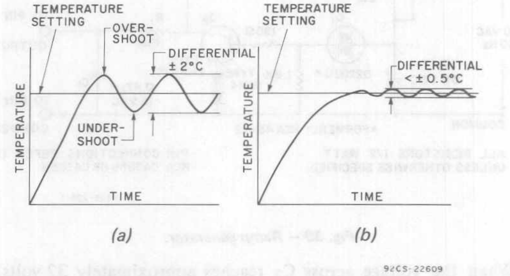


Fig. 28 – Transfer characteristics of (a) on-off and (b) proportional control systems.

Before such a system is implemented, a time base is chosen so that the on-time of the triac is varied within this time base. The ratio of the on-to-off time of the triac within this time interval depends on the thermal time constant of the system and the selected temperature setting. Fig. 29 illustrates the principle of proportional control. For this operation, power is supplied to the load until the ramp voltage reaches a value greater than the dc control signal supplied to the opposite side of the differential amplifier. The triac then remains off for the remainder of the time-base period. As a result, power is "proportioned" to the load in a direct relation to the heat demanded by the system.

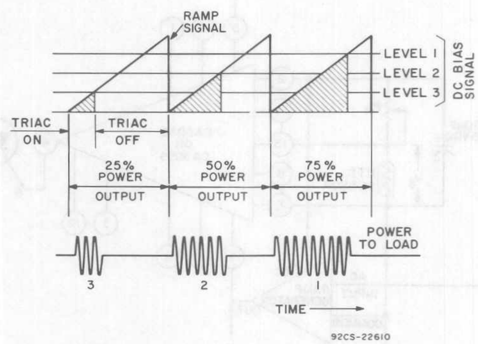


Fig. 29 – Principles of proportional control.

For this application, a simple ramp generator can be realized with a minimum number of active and passive components. A ramp having good linearity is not required for proportional operation because of the nonlinearity of the thermal system and the closed-loop type of control. In the circuit shown in Fig. 30, the ramp voltage is generated when the capacitor C_1 charges through resistors R_0 and R_1. The time base of the ramp is determined by resistors R_2 and R_3, capacitor C_2, and the breakover voltage of the D3202U* diac.

* Formerly RCA 45412

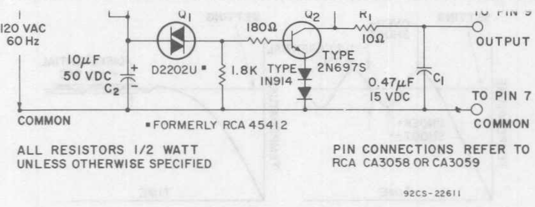


Fig. 30 – Ramp generator.

When the voltage across C_2 reaches approximately 32 volts, the diac switches and turns on the 2N697S transistor and 1N914 diodes. The capacitor C_1 then discharges through the collector-to-emitter junction of the transistor. This discharge time is the retrace or flyback time of the ramp. The circuit shown can generate ramp times ranging from 0.3 to 2.0 seconds through adjustment of R_2. For precise temperature regulation, the time base of the ramp should be shorter than the thermal time constant of the system, but long with respect to the period of the 60-Hz line voltage. Fig. 31 shows a triac connected for the proportional mode.

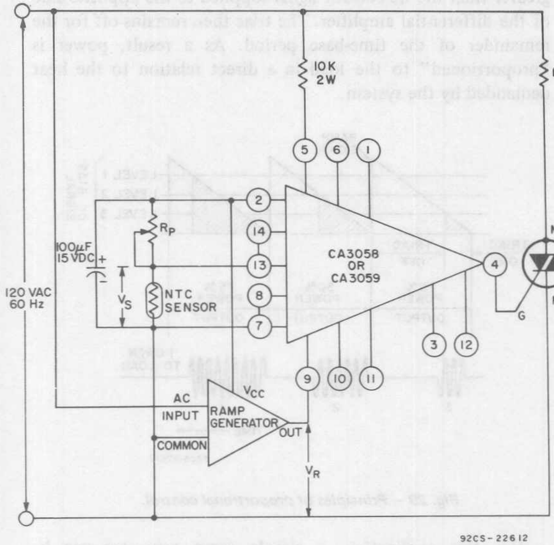


Fig. 31 – CA3058 or CA3059 proportional temperature controller.

Fig. 32(a) shows a dual-output temperature controller that drives two triacs. When the voltage V_s developed across the temperature-sensing network exceeds the reference voltage V_{R1}, motor No. 1 turns on. When the voltage across the network drops below the reference voltage V_{R2}, motor No. 2 turns on. Because the motors are inductive, the currents I_{M1} and I_{M2} are out of phase with the line voltage. This problem is solved by use of the sensitive-gate RCA-40526 triac. The high sensitivity of this device (3 milliamperes maximum) and low latching current (approximately 9 milliamperes) permit synchronous operation of the temperature-controller circuit. In Fig. 32(a), it is apparent that, though the gate pulse V_g of triac Y_1 has elapsed, triac Y_2 is switched on by the current through R_{L1}. The low latching current of the RCA-40526 triac results in dissipation of only 2 watts in R_{L1}, as opposed to 10 to 20 watts when devices that have high latching currents are used.

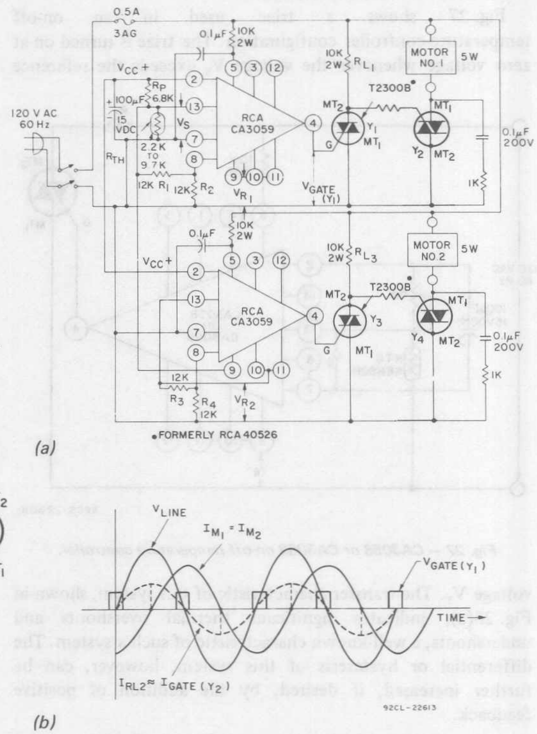


Fig. 32 – Dual output, over-under temperature controller (a) circuit, (b) voltage and current waveforms.

Electric-Heat Application

For electric-heating applications, the RCA-2N5444 40-ampere triac and the zero-voltage switch constitute an optimum pair. Such a combination provides synchronous switching and effectively replaces the heavy-duty contactors which easily degrade as a result of pitting and wearout from the switching transients. The salient features of the 2N5444 40-ampere triac are as follows:

(1) 300-ampere single-surge capability (for operation at 60-Hz),

(2) a typical gate sensitivity of 20 milliamperes in the I(+) and III(+) modes,

(3) low on-state voltage of 1.5 volts maximum at 40 amperes, and

(4) available V_{DROM} equal to 600 volts.

Fig. 33 shows the circuit diagram of a synchronous-switching heat-staging controller that is used for electric heating systems. Loads as heavy as 5 kilowatts are switched sequentially at zero voltage to eliminate RFI and prevent a dip in line voltage that would occur if the full 25 kilowatts were to be switched simultaneously.

Transistor Q_1 and Q_4 are used as a constant-current source to charge capacitor C in a linear manner. Transistor Q_2 acts as a buffer stage. When the thermostat is closed, a ramp voltage is provided at output E_o. At approximately 3-second intervals, each 5-kilowatt heating element is switched onto the power system by its respective triac. When there is no further demand for heat, the thermostat opens, and capacitor C discharges through R_1 and R_2 to cause each triac to turn off in the reverse heating sequence. It should be noted that some half-cycling occurs before the heating element is switched fully on. This condition can be attributed to the inherent dissymmetry of the triac and is further aggravated by the slow-rising ramp voltage applied to one of the inputs. The timing diagram in Fig. 34 shows the turn-on and turn-off sequence of the heating system being controlled.

Seemingly, the basic method shown in Fig. 33 could be modified to provide proportional control in which the number of heating elements switched into the system, under any given

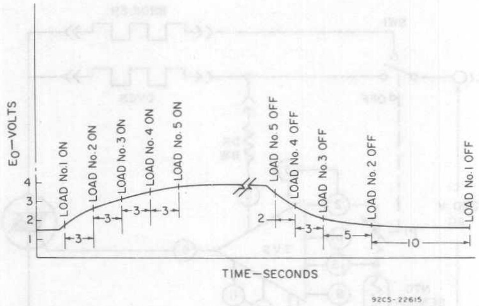


Fig. 34 – Ramp-voltage waveform for the heat-staging controller.

thermal load, would be a function of the BTU's required by the system or the temperature differential between an indoor and outdoor sensor within the total system environment. That is, the closing of the thermostat would not switch in all the heating elements within a short time interval, which inevitably results in undesired temperature excursions, but would switch in only the number of heating elements required to satisfy the actual heat load.

Oven/Broiler Control

Zero-voltage switching is demonstrated in the oven control circuit shown in Fig. 35. In this circuit, a sensor element is included in the oven to provide a closed-loop system for accurate control of the oven temperature.

As shown in Fig. 35, the temperature of the oven can be adjusted by means of potentiometer R_1, which acts, together with the sensor, as a voltage divider at terminal 13. The voltage

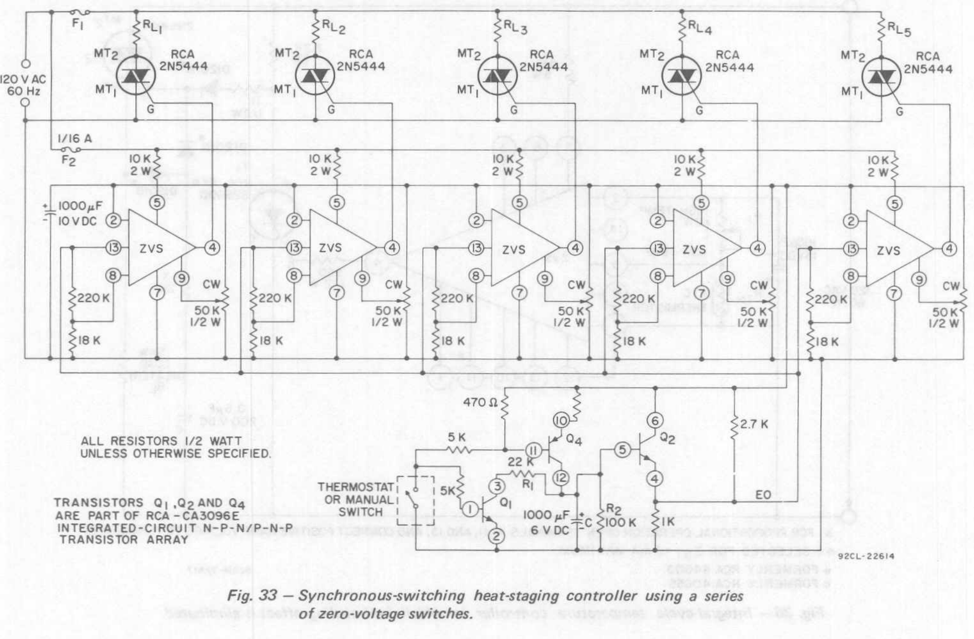


Fig. 33 – Synchronous-switching heat-staging controller using a series of zero-voltage switches.

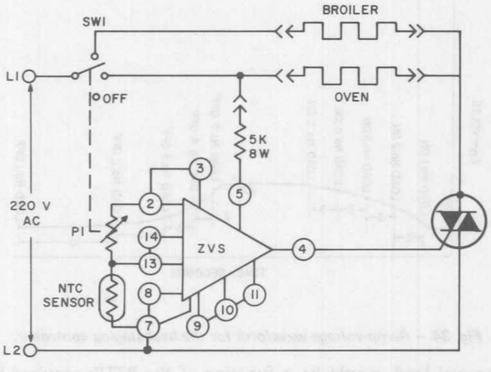


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Fig. 35 – Schematic diagram of basic oven control.

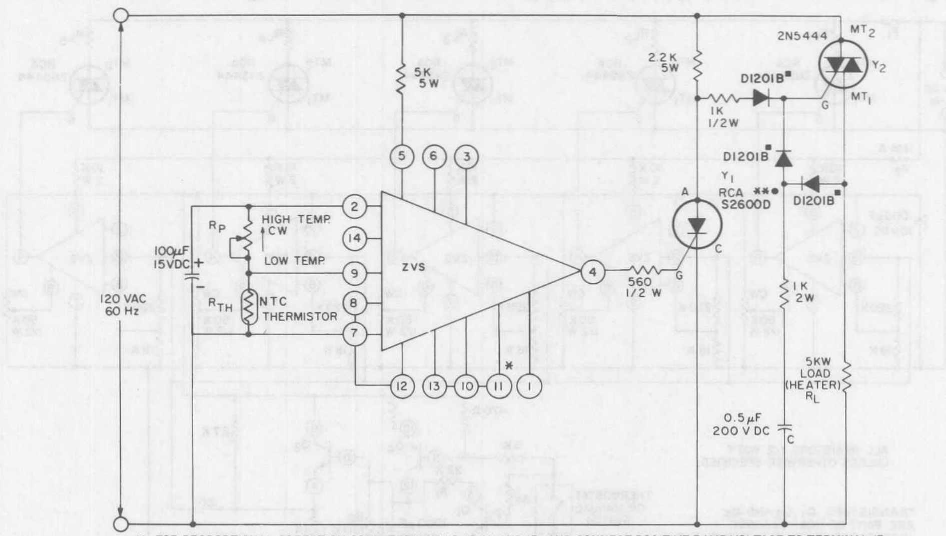
at terminal 13 is compared to the fixed bias at terminal 9 which is set by internal resistors R_4 and R_5. When the oven is cold and the resistance of the sensor is high, transistors Q_2 and Q_4 are off, a pulse of gate current is applied to the triac, and heat is applied to the oven. Conversely, as the desired temperature is reached, the bias at terminal 13 turns the triac off. The closed-loop feature then cycles the oven element on and off to maintain the desired temperature to approximately ±2°C of the set value. Also, as has been noted, external resistors between terminals 13 and 8, and 7 and 8, can be used to vary this temperature and provide hysteresis. In Fig. 11, a circuit that provides approximately 10-per-cent hysteresis is demonstrated.

In addition to allowing the selection of a hysteresis value, the flexibility of the control circuit permits incorporation of other features. A PTC sensor is readily used by interchanging terminals 9 and 13 of the circuit shown in Fig. 35 and substituting the PTC for the NTC sensor. In both cases, the sensor element is directly returned to the system ground or common, as is often desired. Terminal 9 can be connected by external resistors to provide for a variety of biasing, e.g., to match a lower-resistance sensor for which the switching-point voltage has been reduced to maintain the same sensor current.

To accommodate the self-cleaning feature, external switching, which enables both broiler and oven units to be paralleled, can easily be incorporated in the design. Of course, the potentiometer must be capable of a setting such that the sensor, which must be characterized for the high, self-clean temperature, can monitor and establish control of the high-temperature, self-clean mode. The ease with which this self-clean mode can be added makes the over-all solid-state systems cost-competitive with electromechanical systems of comparable capability. In addition, the system incorporates solid-state reliability while being neater, more easily calibrated, and containing less-costly system wiring.

Integral-Cycle Temperature Controller (No half-cycling)

If a temperature controller which is completely devoid of half-cycling and hysteresis is required, then the circuit shown in Fig. 36 may be used. This type of circuit is essential for applications in which half-cycling and the resultant dc component could cause overheating of a power transformer on the utility lines.



* FOR PROPORTIONAL OPERATION OPEN TERMINALS 10, 11, AND 13, AND CONNECT POSITIVE RAMP VOLTAGE TO TERMINAL 13

** SELECTED FOR I_{GT} = 6 mA MAXIMUM.

■ FORMERLY RCA 44003

● FORMERLY RCA 40655

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Fig. 36 – Integral-cycle temperature controller in which half-cycling effect is eliminated.

In the integral-cycle controller, when the temperature being controlled is low, the resistance of the thermistor is high, and an output signal at terminal 4 of zero volts is obtained. The SCR (Y_1), therefore, is turned off. The triac (Y_2) is then triggered directly from the line on positive cycles of the ac voltage. When Y_2 is triggered and supplies power to the load R_L, capacitor C is charged to the peak of the input voltage. When the ac line swings negative, capacitor C discharges through the triac gate to trigger the triac on the negative half-cycle. The diode-resistor-capacitor "slaving network" triggers the triac on negative half-cycle to provide only **integral cycles** of ac power to the load.

When the temperature being controlled reaches the desired value, as determined by the thermistor, then a positive voltage level appears at terminal 4 of the zero-voltage switch. The SCR then starts to conduct at the beginning of the positive input cycle to shunt the trigger current away from the gate of the triac. The triac is then turned off. The cycle repeats when the SCR is again turned OFF by the zero-voltage switch.

The circuit shown in Fig. 37 is similar to the configuration in Fig. 36 except that the protection circuit incorporated in the zero-voltage switch can be used. In this new circuit, the NTC sensor is connected between terminals 7 and 13, and transistor Q_o inverts the signal output at terminal 4 to nullify the phase reversal introduced by the SCR (Y_1). The internal power supply of the zero-voltage switch supplies bias current to transistor Q_o.

Of course, the circuit shown in Fig. 37 can readily be converted to a **true proportional integral-cycle temperature controller** simply by connection of a positive-going ramp voltage to terminal 9 (with terminals 10 and 11 open), as previously discussed in this Note.

Thermocouple Temperature Control

Fig. 38 shows the CA3080A operating as a pre-amplifier for the zero-voltage switch to form a zero-voltage switching circuit for use with thermocouple sensors.

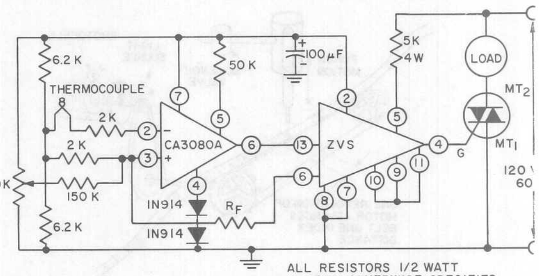
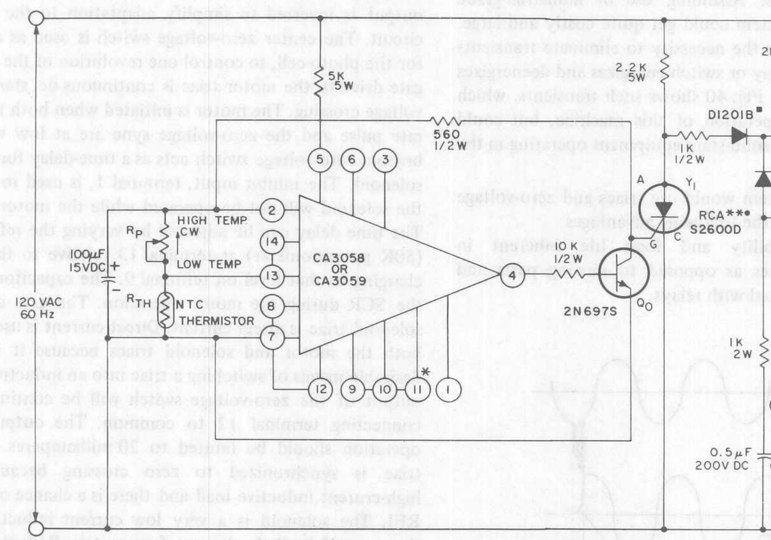


Fig. 38 – Thermocouple temperature control with zero-voltage switching.



* FOR PROPORTIONAL OPERATION OPEN TERMINALS 9,10 AND 11 AND CONNECT POSTIVE RAMP VOLTAGE TO TERMINAL 9
**SELECTED FOR I_{GT}=6 mA MAXIMUM
▪FORMERLY RCA 44003
•FORMERLY RCA 40655

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Fig. 37 – CA3058 or CA3059 integral-cycle temperature controller that features a protection circuit and no half-cycling effect.

MACHINE CONTROL AND AUTOMATION

The earlier section on interfacing techniques indicated several techniques of controlling ac loads through a logic system. Many types of automatic equipment are not complex enough or large enough to justify the cost of a flexible logic system. A special circuit, designed only to meet the control requirements of a particular machine, may prove more economical. For example, consider the simple machine shown in Fig. 39; for each revolution of the motor, the belt is advanced a prescribed distance, and the strip is then punched. The machine also has variable speed capability.

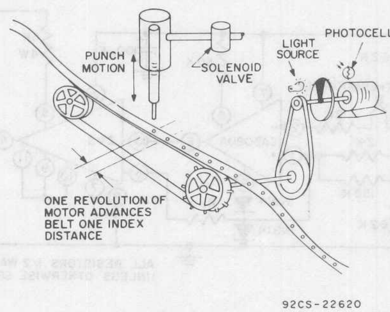


Fig. 39 – Step-and-punch machine.

The typical electromechanical control circuit for such a machine might consist of a mechanical cambank driven by a separate variable speed motor, a time delay relay, and a few logic and power relays. Assuming use of industrial-grade controls, the control system could get quite costly and large. Of greater importance is the necessity to eliminate transients generated each time a relay or switch energizes and deenergizes the solenoid and motor. Fig. 40 shows such transients, which might not affect the operation of this machine, but could affect the more sensitive solid-state equipment operating in the area.

A more desirable system would use triacs and zero-voltage switching to incorporate the following advantages:

a. Increased reliability and long life inherent in solid-state devices as opposed to moving parts and contacts associated with relays.

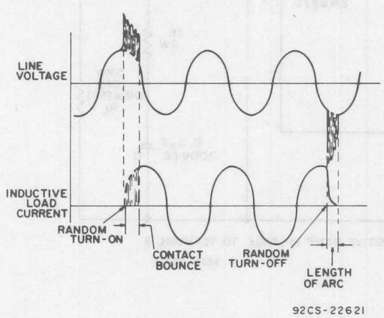


Fig. 40 – Transients generated by relay-contact bounce and non-zero turn-off of inductive load.

b. Minimized generation of EMI/RFI using zero-voltage switching techniques in conjunction with thyristors.

c. Elimination of high-voltage transients generated by relay-contact bounce and contacts breaking inductive loads, as shown in Fig. 39.

d. Compactness of the control system.

The entire control system could be on one printed-circuit board, and an over-all cost advantage would be achieved. Fig. 41 is a timing diagram for the proposed solid-state

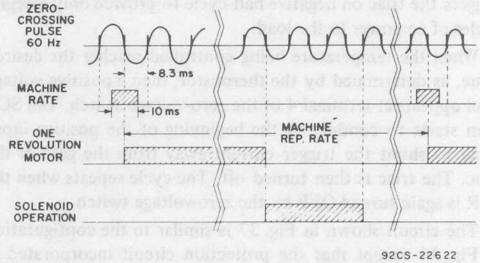


Fig. 41 – Timing diagram for proposed solid-state machine control.

machine control, and Fig. 42 is the corresponding control schematic. A variable-speed machine repetition rate pulse is set up using either a unijunction oscillator or a transistor astable multivibrator in conjunction with a 10-millisecond one-shot multivibrator. The first zero-voltage switch in Fig. 42 is used to synchronize the entire system to zero-voltage crossing. Its output is inverted to simplify adaptation to the rest of the circuit. The center zero-voltage switch is used as an interface for the photo-cell, to control one revolution of the motor. The gate drive to the motor triac is continuous dc, starting at zero voltage crossing. The motor is initiated when both the machine rate pulse and the zero-voltage sync are at low voltage. The bottom zero-voltage switch acts as a time-delay for pulsing the solenoid. The inhibit input, terminal 1, is used to assure that the solenoid will not be operated while the motor is running. The time delay can be adjusted by varying the reference level (50K potentiometer) at terminal 13 relative to the capacitor charging to that level on terminal 9. The capacitor is reset by the SCR during the motor operation. The gate drive to the solenoid triac is direct current. Direct current is used to trigger both the motor and solenoid triacs because it is the most desirable means of switching a triac into an inductive load. The output of the zero-voltage switch will be continuous dc by connecting terminal 12 to common. The output under dc operation should be limited to 20 milliamperes. The motor triac is synchronized to zero crossing because it is a high-crurent inductive load and there is a chance of generating RFI. The solenoid is a very low current inductive load, so there would be little chance of generating RFI: therefore, the initial triac turn-on can be random, which simplifies the circuitry.

This example shows the versatility and advantages of the RCA zero-voltage switch used in conjunction with triacs as interfacing and control elements for machine control.

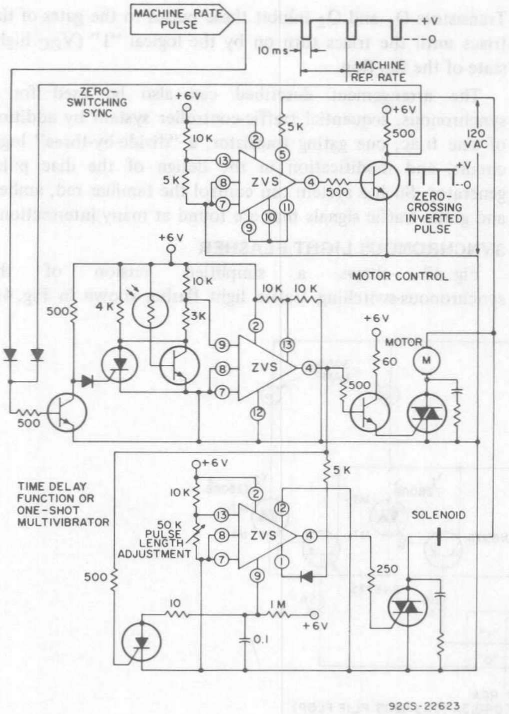


Fig. 42 – Schematic of proposed solid-state machine control.

400-Hz TRIAC APPLICATIONS

The increased complexity of aircraft control systems, and the need for greater reliability than electromechanical switching can offer, has led to the use of solid-state power switching in aircraft. Because 400-Hz power is used almost universally in aircraft systems, RCA offers a complete line of triacs rated for 400-Hz applications. Use of the RCA zero-voltage switch in conjunction with these 400-Hz triacs results in a minimum of RFI, which is especially important in aircraft.

Areas of application for 400-Hz triacs in aircraft include:

a. Heater controls for food-warming ovens and for windshield defrosters.
b. Lighting controls for instrument panels and cabin illumination
c. Motor controls
d. Solenoid controls
e. Power-supply switches

Lamp dimming is a simple triac application that demonstrates an advantage of 400-Hz power over 60-Hz power. Fig. 43 shows the adjustment of lamp intensity by phase control of the 60-Hz line voltage. RFI is generated by the step functions of power each half cycle, requiring extensive filtering. Fig. 44 shows a means of controlling power to the lamp by the zero-voltage-switching technique. Use of 400-Hz power makes possible the elimination of complete or half cycles within a period (typically 17.5 milliseconds)

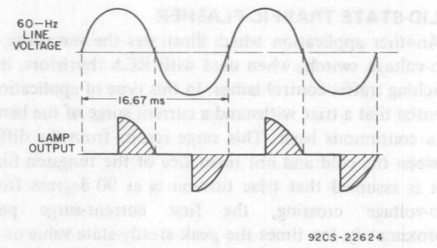


Fig. 43 – Waveforms for 60-Hz phase-controlled lamp dimmer.

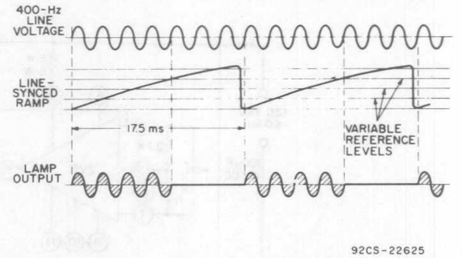


Fig. 44 – Waveforms for 400-Hz zero-voltage-switched lamp dimmer.

without noticeable flicker. Fourteen different levels of lamp intensity can be obtained in this manner. A line-synced ramp is set up with the desired period and applied to terminal No. 9 of the differential amplifier within the zero-voltage switch, as shown in Fig. 45. The other side of the differential amplifier (terminal No. 13) uses a variable reference level, set by the 50K potentiometer. A change of the potentiometer setting changes the lamp intensity.

In 400-Hz applications it may be necessary to widen and shift the zero-voltage switch output pulse (which is typically 12 microseconds wide and centered on zero voltage crossing), to assure that sufficient latching current is available. The 4K resistor (terminal No. 12 to common) and the 0.015-microfarad capacitor (terminal No. 5 to common) are used for this adjustment.

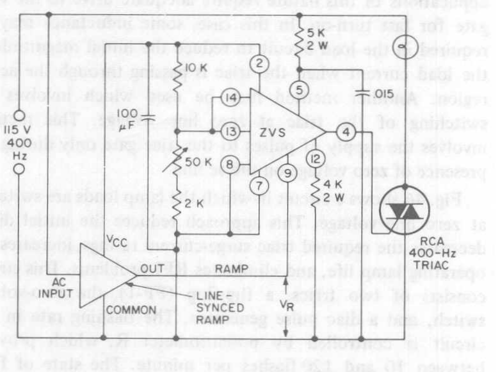


Fig. 45 – Circuit diagram for 400-Hz zero-voltage-switched lamp dimmer.

SOLID-STATE TRAFFIC FLASHER

Another application which illustrates the versatility of the zero-voltage switch, when used with RCA thyristors, involves switching traffic-control lamps. In this type of application, it is essential that a triac withstand a current surge of the lamp load on a continuous basis. This surge results from the difference between the cold and hot resistance of the tungsten filament. If it is assumed that triac turn-on is at 90 degrees from the zero-voltage crossing, the first current-surge peak is approximately ten times the peak steady-state value or fifteen times the steady-state rms value. The second current-surge peak is approximately four times the steady-state rms value.

Transistors Q_1 and Q_2 inhibit these pulses to the gates of the triacs until the triacs turn on by the logical "1" (V_{CC} high) state of the flip-flop.

The arrangement described can also be used for a synchronous, sequential traffic-controller system by addition of one triac, one gating transistor, a "divide-by-three" logic circuit, and modification in the design of the diac pulse generator. Such a system can control the familiar red, amber, and green traffic signals that are found at many intersections.

SYNCHRONOUS LIGHT FLASHER

Fig. 47 shows a simplified version of the synchronous-switching traffic light flasher shown in Fig. 46.

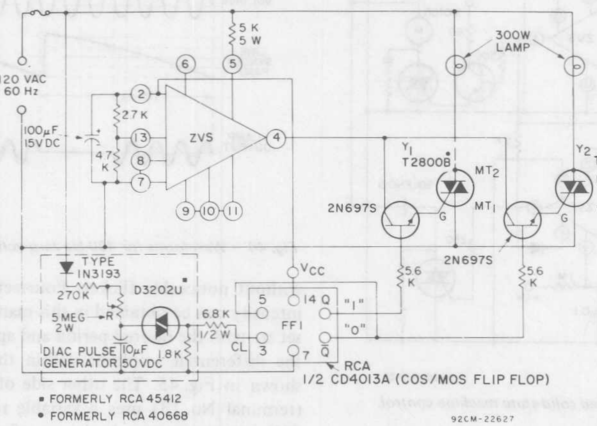


Fig. 46 – Synchronous-switching traffic flasher.

When the triac randomly switches the lamp, the rate of current rise di/dt is limited only by the source inductance. The triac di/dt rating may be exceeded in some power systems. In many cases, exceeding the rating results in excessive current concentrations in a small area of the device which may produce a hot spot and lead to device failure. Critical applications of this nature require adequate drive to the triac gate for fast turn-on. In this case, some inductance may be required in the load circuit to reduce the initial magnitude of the load current when the triac is passing through the active region. Another method may be used which involves the switching of the triac at zero line voltage. This method involves the supply of pulses to the triac gate only during the presence of zero voltage on the ac line.

Fig. 46 shows a circuit in which the lamp loads are switched at zero line voltage. This approach reduces the initial di/dt, decreases the required triac surge-current ratings, increases the operating lamp life, and eliminates RFI problems. This circuit consists of two triacs, a flip-flop (FF-1), the zero-voltage switch, and a diac pulse generator. The flashing rate in this circuit is controlled by potentiometer R, which provides between 10 and 120 flashes per minute. The state of FF-1 determines the triggering of triacs Y_1 or Y_2 by the output pulses at terminal 4 generated by the zero-crossing circuit.

Flash rate is set by use of the curve shown in Fig. 16. If a more precise flash rate is required, the ramp generator described previously may be used. In this circuit, ZVS_1 is the master control unit and ZVS_2 is slaved to the output of ZVS_1 through its inhibit terminal (terminal 1). When power is applied to lamp No. 1, the voltage of terminal 6 on ZVS_1 is high and ZVS_2 is inhibited by the current in R_x. When lamp

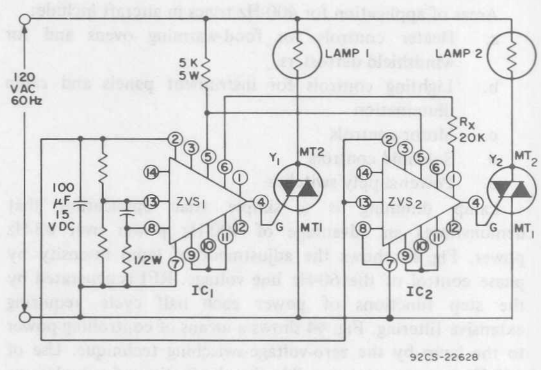


Fig. 47 – Synchronous light flasher.

No. 1 is off, ZVS_2 is not inhibited, and triac Y_2 can fire. The power supplies operate in parallel. The on-off sensing amplifier in ZVS_2 is not used.

TRANSIENT-FREE SWITCH CONTROLLERS

The zero-voltage switch can be used as a simple solid-state switching device that permits ac currents to be turned on or off with a minimum of electrical transients and circuit noise.

The circuit shown in Fig. 48 is connected so that, after the control terminal 14 is opened, the electronic logic waits until the power-line voltage reaches a zero crossing before power is applied to the load Z_L. Conversely, when the control terminals are shorted, the load current continues until it reaches a zero crossing. This circuit can switch a load at zero current whether it is resistive or inductive.

The circuit shown in Fig. 49 is connected to provide the opposite control logic to that of the circuit shown in Fig. 48. That is, when the switch is closed, power is supplied to the load, and when the switch is opened, power is removed from the load.

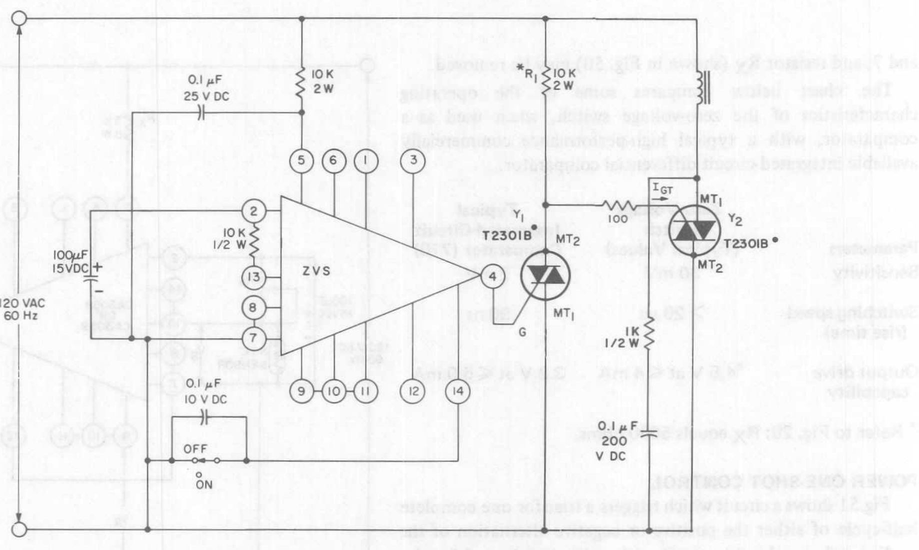
In both configurations, the maximum rms load current that can be switched depends on the rating of triac Y_2. If Y_2 is an RCA-2N5444 triac, an rms current of 40 amperes can be switched.

DIFFERENTIAL COMFARATOR FOR INDUSTRIAL USE

Differential comparators have found widespread use as limit detectors which compare two analog input signals and provide a go/no-go, logic 'one" or logic "zero" output, depending upon the relative magnitudes of these signals. Because the signals are often at very low voltage levels and very accurate discrimination is normally required between them, differential comparators in many cases employ differential amplifiers as a basic building block. However, in many industrial control applications, a high-performance differential comparator is not required. That is, high resolution, fast switching speed, and similar features are not essential. The zero-voltage switch is ideally suited for use in such applications. Connection of terminal 12 to terminal 7 inhibits the zero-voltage threshold detector of the zero-voltage switch, and the circuit becomes a differential comparator.

Fig. 50 shows the circuit arrangement for use of the zero-voltage switch as a differential comparator. In this application, no external dc supply is required, as is the case with most commercially available integrated-circuit comparators; of course, the output-current capability of the zero-voltage switch is reduced because the circuit is operating in the dc mode. The 1000-ohm resistor R_G, connected between terminal 4 and the gate of the triac, limits the output current to approximately 3 milliamperes.

When the zero-voltage switch is connected in the dc mode, the drive current for terminal 4 can be determined from a curve of the external load current as a function of dc voltage from terminals 2 and 7. This curve is shown in the technical bulletin for RCA integrated-circuit zero-voltage switches, File No. 490. Of course, if additional output current is required, an external dc supply may be connected between terminals 2



*IF Y_2, FOR EXAMPLE, IS A 40-AMPERE TRIAC, THEN R_1 MUST BE DECREASED TO SUPPLY SUFFICIENT I_{GT} FOR Y_2.

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Fig. 48 – Zero-voltage switch transient-free switch controller in which power is supplied to the load when the switch is open.

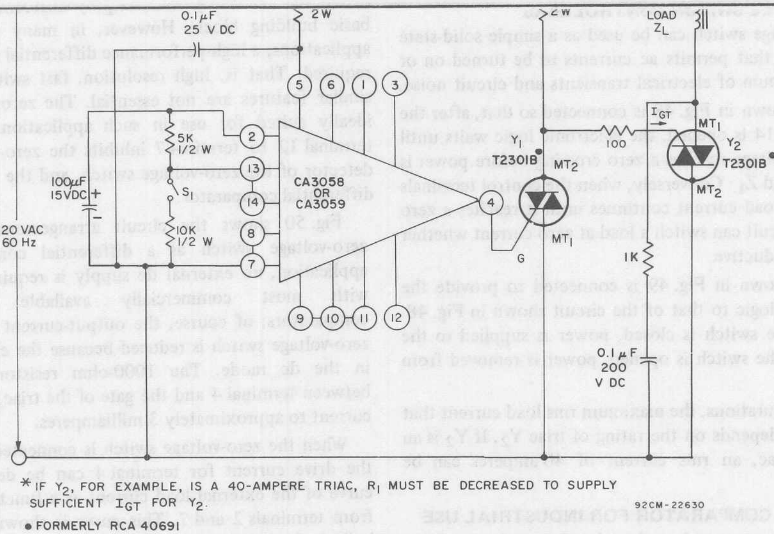

Fig. 49 – Zero-voltage switch transient-free switch controller in which power is applied to the load when the switch is closed.

and 7, and resistor R_X (shown in Fig. 50) may be removed.

The chart below compares some of the operating characteristics of the zero-voltage switch, when used as a comparator, with a typical high-performance commercially available integrated-circuit differential comparator.

Parameters	Zero-Voltage Switch (Typical Values)	Typical Integrated-Circuit Comparator (710)
Sensitivity	30 mV	2 mV
Switching speed (rise time)	> 20 μs	90 ns
Output drive capability	*4.5 V at ≤ 4 mA	3.2 V at ≤ 5.0 mA

* Refer to Fig. 20; R_X equals 5000 ohms.

POWER ONE-SHOT CONTROL

Fig.51 shows a circuit which triggers a triac for one complete half-cycle of either the positive or negative alternation of the ac line voltage. In this circuit, triggering is initiated by the push button PB-1, which produces triggering of the triac near zero voltage even though the button is randomly depressed during the ac cycle. The triac does not trigger again until the button is released and again depressed. This type of logic is required for the solenoid drive of electrically operated stapling

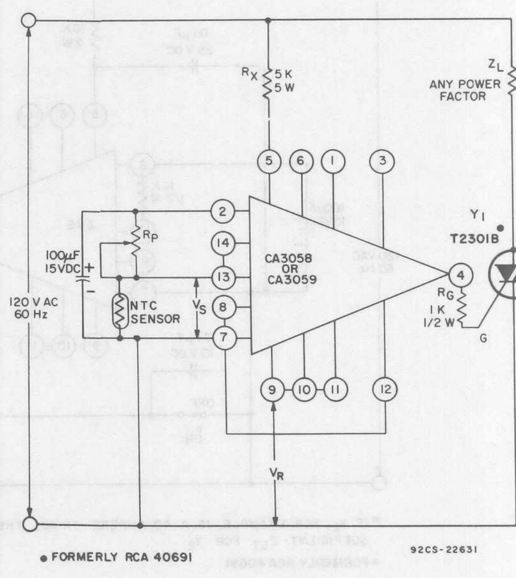

Fig. 50 – Differential comparator using the CA3058 or CA3059 integrated-circuit zero-voltage switch.

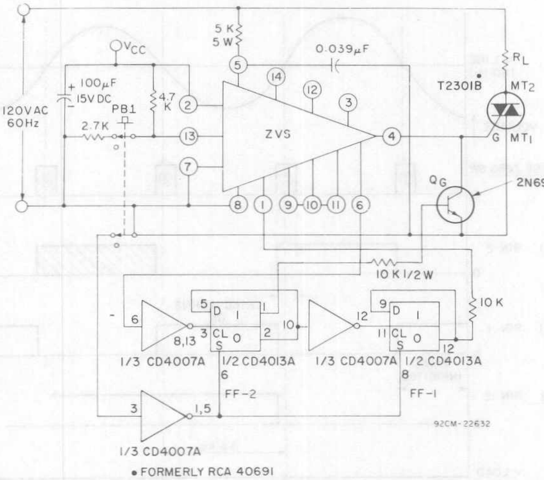

Fig. 51 – Block diagram of a power one-shot control using a zero-voltage switch.

guns, impulse hammers, and the like, where load-current flow is required for only one complete half-cycle. Such logic can also be adapted to keyboard consoles in which contact bounce produces transmission of erroneous information.

In the circuit of Fig. 51, before the button is depressed, both flip-flop outputs are in the "zero" state. Transistor Q_G is biased on by the output of flip-flop FF-1. The differential comparator which is part of the zero-voltage switch is initially biased to inhibit output pulses. When the push button is depressed, pulses are generated, but the state of Q_G determines the requirement for their supply to the triac gate. The first pulse generated serves as a "framing pulse" and does not trigger the triac but toggles FF-1. Transistor Q_G is then turned off. The second pulse triggers the triac and FF-1 which, in turn, toggles the second flip-flop FF-2. The output of FF-2 turns on transistor Q_7, as shown in Fig. 52, which inhibits all further output pulses. When the pushbutton is released, the circuit resets itself until the process is repeated with the button. Fig. 53 shows the timing diagram for the described operating sequence.

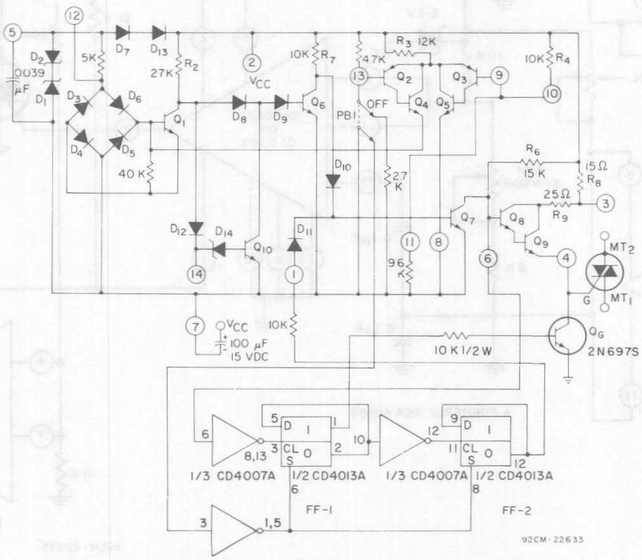

Fig. 52 – Circuit diagram for the power one-shot control.

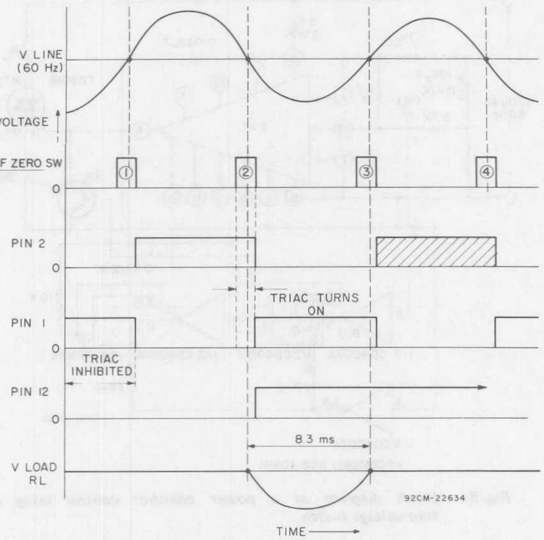

Fig. 53 – Timing diagram for the power one-shot control.

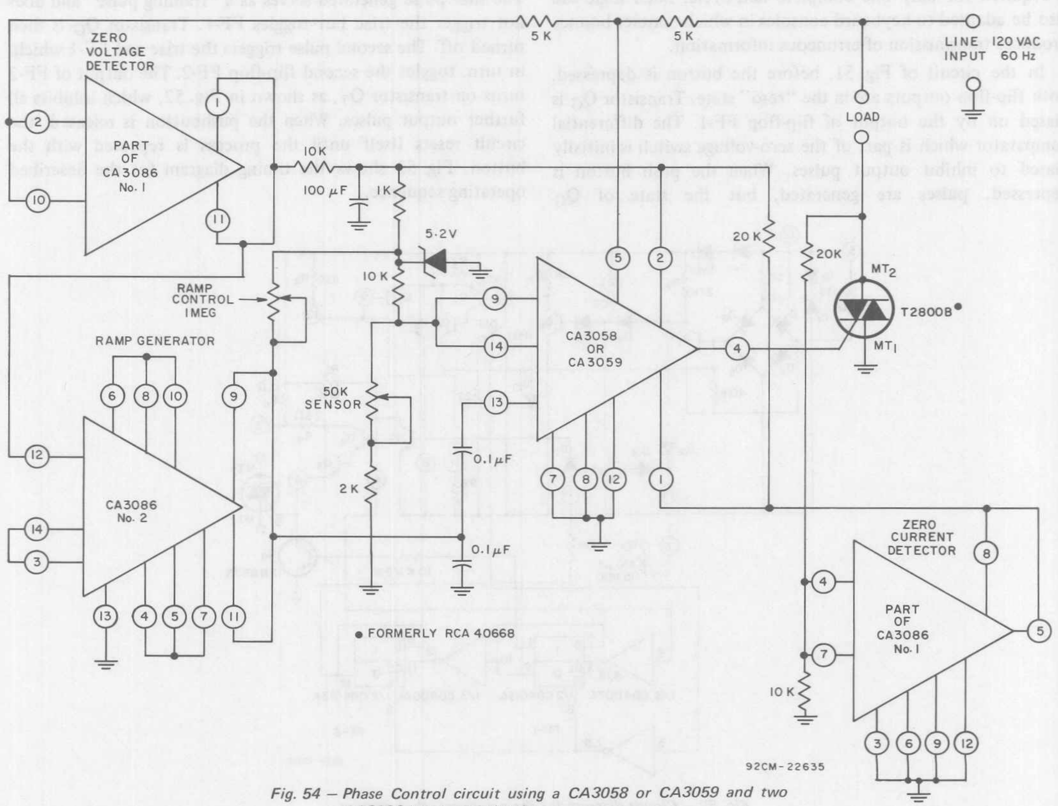

Fig. 54 – Phase Control circuit using a CA3058 or CA3059 and two CA3086 integrated-circuits.

PHASE CONTROL CIRCUIT

Fig. 54 shows a circuit using a CA3058 or CA3059 zero-voltage switch together with two CA3086 integrated-circuit transistor arrays to form a phase-control circuit. This circuit is specifically designed for speed control of ac induction motors, but may also be used as a light dimmer. The circuit, which can be operated from a line frequency of 50-Hz to 400-Hz, consists of a zero-voltage detector, a line-synchronized ramp generator, a zero-current detector, and a line-derived control circuit (i.e., the zero-voltage switch). The zero-voltage detector (part of CA3086 No. 1) and the ramp generator (CA3086 No. 2) provide a line-synchronized ramp-voltage output to terminal 13 of the zero-voltage switch. The ramp voltage, which has a starting voltage of 1.8 volts, starts to rise after the line voltage passes the zero point. The ramp generator has an oscillation frequency of twice the incoming line frequency. The slope of the ramp voltage can be adjusted by variation of the resistance of the 1-megohm ramp-control potentiometer. The output phase can be controlled easily to provide 180° firing of the triac by programming the voltage at terminal 9 of the zero-voltage switch. The basic operation of the zero-voltage switch driving a thyristor with an inductive load was explained previously in the discussion on switching of inductive loads.

TRIAC POWER CONTROLS FOR THREE-PHASE SYSTEMS

This section describes recommended configurations for power-control circuits intended for use with both inductive and resistive balanced three-phase loads. The specific design requirements for each type of loading condition are discussed.

In the power-control circuits described, the integrated-circuit zero-voltage switch is used as the trigger circuit for the power triacs. The following conditions are also imposed in the design of the triac control circuits:

1. The load should be connected in a three-wire configuration with the triacs placed external to the load; eiter delta or wye arrangements may be used. Four-wire loads in wye configurations can be handled as three independent single-phase systems. Delta configurations in which a triac is connected within each phase rather than in the incoming lines can also be handled as three independent single-phase systems.
2. Only one logic command signal is available for the control circuits. This signal must be electrically isolated from the three-phase power system.
3. Three separate triac gating signals are required.
4. For operation with resistive loads, the zero-voltage switching technique should be used to minimize any radio-frequency interference (RFI) that may be generated.

Isolation of DC Logic Circuitry

As explained earlier under **Special Application Considerations**, isolation of the dc logic circuitry* from the ac line, the triac, and the load circuit is often desirable even in many single-phase power-control . applications. In control circuits for polyphase power systems, however, this type of isolation is essential, because the common point of the dc logic circuitry cannot be referenced to a common line in all phases.

In the three-phase circuits described in this section, photo-optic techniques (i.e., photo-coupled isolators) are used to provide the electrical isolation of the dc logic command signal from the ac circuits and the load. The photo-coupled isolators consist of an infrared light-emitting diode aimed at a silicon photo transistor, coupled in a common package. The light-emitting diode is the input section, and the photo transistor is the output section. The two components provide a voltage isolation typically of 1500 volts. Other isolation techniques, such as pulse transformers, magnetoresistors, or reed relays, can also be used with some circuit modifications.

Resistive Loads

Fig. 55 illustrates the basic phase relationships of a balanced three-phase resistive load, such as may be used in heater applications, in which the application of load power is

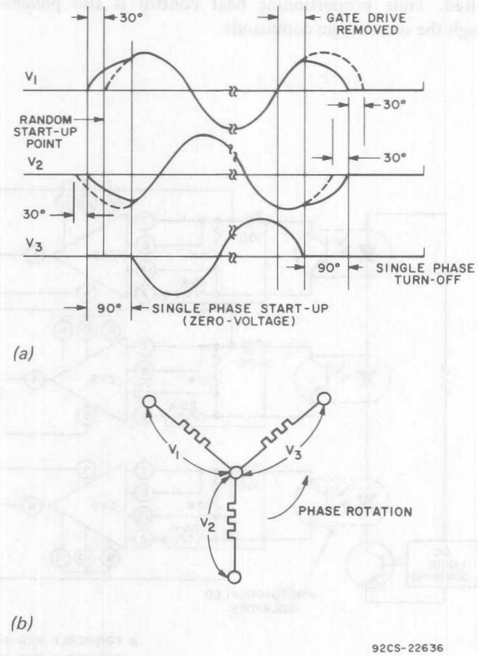

Fig. 55 – Voltage phase relationship for a three-phase resistive load when the application of load power is controlled by zero-voltage switching: (a) voltage waveforms, (b) load-circuit orientation of voltages. (The dashed lines indicate the normal relationship of the phases under steady-state conditions. The deviation at start-up and turn-off should be noted.)

* The dc logic circuitry provides the low-level electrical signal that dictates the state of the load. For temperature controls, the dc logic circuitry includes a temperature sensor for feedback. The RCA integrated-circuit zero-voltage switch, when operated in the dc mode with some additional circuitry, can replace the dc logic circuitry for temperature controls.

voltage.

2. A single phase of a wye configuration type of three-wire system cannot be turned on.
3. Two phases must be turned on for initial starting of the system. These two phases form a single-phase circuit which is out of phase with both of its component phases. The single-phase circuit leads one phase by 30 degrees and lags the other phase by 30 degrees.

These conditions indicate that in order to maintain a system in which no appreciable RFI is generated by the switching action from initial starting through the steady-state operating condition, the system must first be turned on, by zero-voltage switching, as a single-phase circuit and then must revert to synchronous three-phase operation.

Fig. 56 shows a simplified circuit configuration of a three-phase heater control that employs zero-voltage synchronous switching in the steady-state operating condition, with random starting. In this system, the logic command to turn on the system is given when heat is required, and the command to turn off the system is given when heat is not required. Time proportioning heat control is also possible through the use of logic commands.

A zero-voltage crossing relative to their particular phase. A balanced three-phase sensing circuit is set up with the three zero-voltage switches each connected to a particular phase on their common side (terminal 7) and referenced at their high side (terminal 5), through the current-limiting resistors R4, R5, and R6, to an established artificial neutral point. This artificial neutral point is electrically equivalent to the inaccessible neutral point of the wye type of three-wire load and, therefore, is used to establish the desired phase relationships. The same artificial neutral point is also used to establish the proper phase relationships for a delta type of three-wire load. Because only one triac is pulsed on at a time, the diodes (D1, D2, and D3) are necessary to trigger the opposite-polarity triac, and, in this way, to assure initial latching-on of the system. The three resistors (R1, R2, and R3) are used for current limiting of the gate drive when the opposite-polarity triac is triggered on by the line voltage.

In critical applications that require suppression of all generated RFI, the circuit shown in Fig. 57 may be used. In addition to synchronous steady-state operating conditions, this circuit also incorporates a zero-voltage starting circuit. The start-up condition is zero-voltage synchronized to a

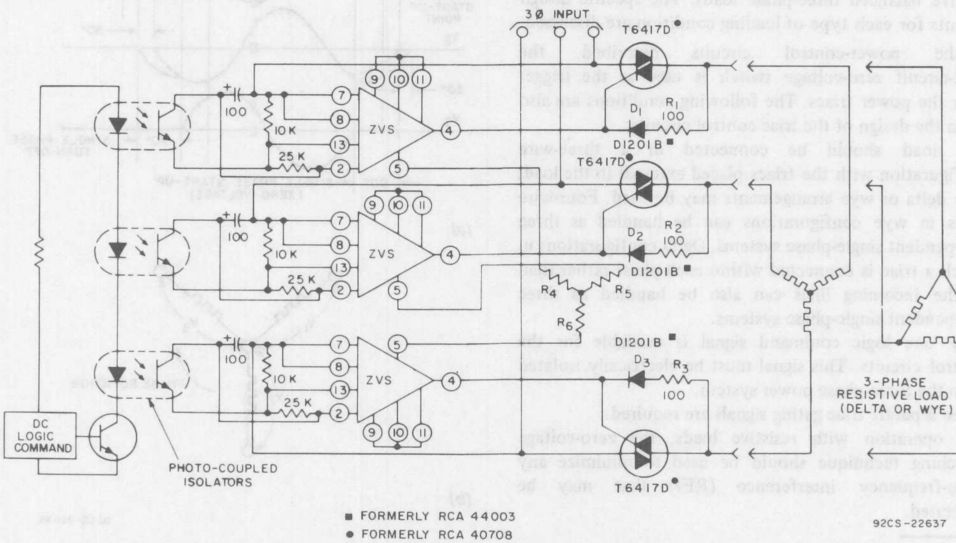

Fig. 56 – Simplified diagram of a three-phase heater control that employs zero-voltage synchronous switching in the steady-state operating conditions.

single-phase, 2-wire, line-to-line circuit, comprised of phases A and B. The logic command engages the single-phase start-up zero-voltage switch and three-phase photo-coupled isolators OC13, OC14, OC15 through the photo-coupled isolators OC11 and OC12. The single-phase zero-voltage switch, which is synchronized to phases A and B, starts the system at zero voltage. As soon as start-up is accomplished, the three photo-coupled isolators OC13, OC14, and OC15 take control, and three-phase synchronization begins. When the "logic command" is turned off, all control is ended, and the triacs automatically turn off when the sine-wave current decreases to zero. Once the first phase turns off, the other two will turn off simultaneously, 90° later, as a single-phase line-to-line circuit, as is apparent from Fig. 55.

Inductive Loads

For inductive loads, zero-voltage turn-on is not generally required because the inductive current cannot increase instantaneously; therefore, the amount of RFI generated is usually negligible. Also, because of the lagging nature of the inductive current, the triacs cannot be pulse-fired at zero voltage. There are several ways in which the zero-voltage switch may be interfaced to a triac for inductive-load applications. The most direct approach is to use the zero-voltage switch in the dc mode, i.e., to provide a continuous dc output instead of pulses at points of zero-voltage crossing. This mode of operation is accomplished by connection of terminal 12 to terminal 7, as shown in Fig. 58. The output of the zero-voltage switch should also be

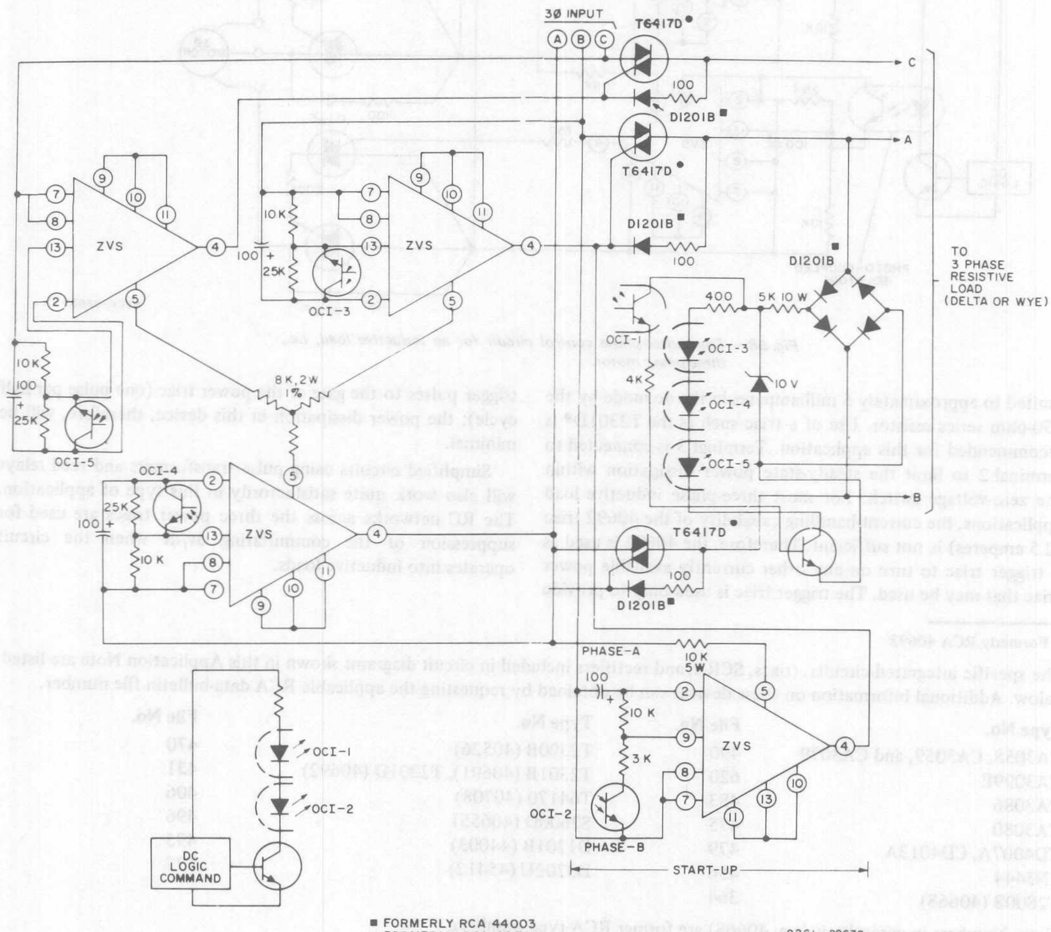

Fig. 57 – Three-phase power control that employs zero-voltage synchronous switching both for steady-state operation and for starting.

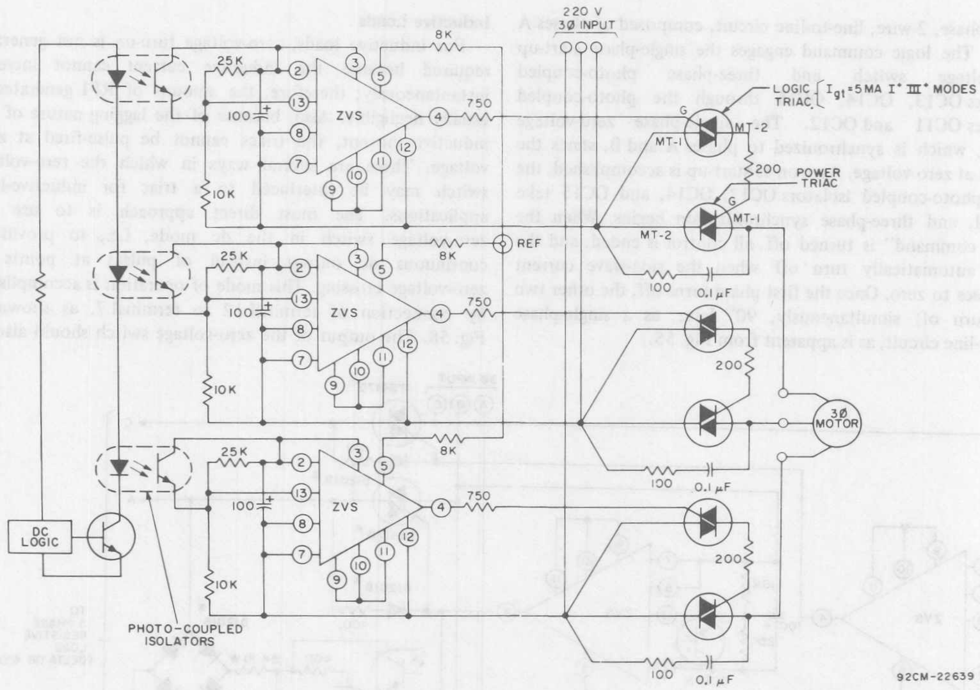

Fig. 58 – Triac three-phase control circuit for an inductive load, i.e., three-phase motor.

limited to approximately 5 milliamperes in the dc mode by the 750-ohm series resistor. Use of a triac such as the T2301D* is recommended for this application. Terminal 3 is connected to terminal 2 to limit the steady-state power dissipation within the zero-voltage switch. For most three-phase inductive load applications, the current-handling capability of the 40692 triac (2.5 amperes) is not sufficient. Therefore, the 40692 is used as a trigger triac to turn on any other currently available power triac that may be used. The trigger triac is used only to provide trigger pulses to the gate of the power triac (one pulse per half cycle); the power dissipation in this device, therefore, will be minimal.

Simplified circuits using pulse transformers and reed relays will also work quite satisfactorily in this type of application. The RC networks across the three power triacs are used for suppression of the commutating dv/dt when the circuit operates into inductive loads.

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* Formerly RCA 40692

The specific integrated-circuits, triacs, SCR's, and rectifiers included in circuit diagrams shown in this Application Note are listed below. Additional information on these devices can be obtained by requesting the applicable RCA data-bulletin file number.

Type No.	File No.	Type No.	File No.
CA3058, CA3059, and CA3079	490	T2300B (40526)	470
CA3099E	620	T2301B (40691), T2301D (40692)	431
CA3086	483	T64170 (40708)	406
CA3080	475	S2600D (40655)	496
CD4007A, CD4013A	479	D1201B (44003)	495
2N5444	456	D3202U (45412)	577
T2800B (40668)	364		

Note: Numbers in parenthesis (e.g. 40668) are former RCA type numbers.

Guide to RCA Solid-State Devices

TA147	1N539	SSD-206	255	3	RECT
TA148	1N540	SSD-206	255	3	RECT
TA149	1N1095	SSD-206	255	3	RECT
TA1000	1N547	SSD-206	255	3	RECT
TA1003	1N440B	SSD-206	252	5	RECT
TA1004	1N441B	SSD-206	252	5	RECT
TA1005	1N442B	SSD-206	252	5	RECT
TA1006	1N443B	SSD-206	252	5	RECT
TA1007	1N444B	SSD-206	252	5	RECT
TA1008	1N445B	SSD-206	252	5	RECT
TA1011	1N2859A	SSD-206	265	91	RECT
TA1012	1N2860A	SSD-206	265	91	RECT
TA1013	1N2861A	SSD-206	265	91	RECT
TA1014	1N2862A	SSD-206	265	91	RECT
TA1015	1N2863A	SSD-206	265	91	RECT
TA1016	1N2864A	SSD-206	265	91	RECT
TA1049	1N248C	SSD-206	287	6	RECT
TA1050	1N249C	SSD-206	287	6	RECT
TA1051	1N250C	SSD-206	287	6	RECT
TA1052	1N1195A	SSD-206	287	6	RECT
TA1053	1N1196A	SSD-206	287	6	RECT
TA1054	1N1197A	SSD-206	287	6	RECT
TA1055	1N1198A	SSD-206	287	6	RECT
TA1066	1N2858A	SSD-206	265	91	RECT
TA1076	1N1199A	SSD-206	283	20	RECT
TA1077	1N1200A	SSD-206	283	20	RECT
TA1078	1N1202A	SSD-206	283	20	RECT
TA1079	1N1203A	SSD-206	283	20	RECT
TA1080	1N1204A	SSD-206	283	20	RECT
TA1081	1N1205A	SSD-206	283	20	RECT
TA1082	1N1206A	SSD-206	283	20	RECT
TA1085	1N1183A	SSD-206	291	38	RECT
TA1086	1N1184A	SSD-206	291	38	RECT
TA1087	1N1186A	SSD-206	291	38	RECT
TA1095	1N1197A	SSD-206	287	6	RECT
TA1096	1N3194	SSD-206	294	41	RECT
TA1111	1N3193	SSD-206	294	41	RECT
TA1112	1N3195	SSD-206	294	41	RECT
TA1113	1N3196	SSD-206	294	41	RECT
TA1120	1N3253	SSD-206	294	41	RECT
TA1121	1N3254	SSD-206	294	41	RECT
TA1122	1N3255	SSD-206	294	41	RECT
TA1123	1N3256	SSD-206	294	41	RECT
TA1171	2N681	SSD-206	225	96	SCR
TA1172	2N682	SSD-206	225	96	SCR
TA1173	2N683	SSD-206	225	96	SCR
TA1174	2N684	SSD-206	225	96	SCR
TA1175	2N685	SSD-206	225	96	SCR
TA1176	2N686	SSD-206	225	96	SCR
TA1177	2N687	SSD-206	225	96	SCR
TA1178	2N688	SSD-206	225	96	SCR
TA1179	2N689	SSD-206	225	96	SCR
TA1182	1N3563	SSD-206	294	41	RECT
TA1204	2N1842A	SSD-206	234	28	SCR
TA1205	2N1843A	SSD-206	234	28	SCR
TA1206	2N1844A	SSD-206	234	28	SCR
TA1207	2N1845A	SSD-206	234	28	SCR
TA1208	2N1846A	SSD-206	234	28	SCR
TA1209	2N1847A	SSD-206	234	28	SCR
TA1210	2N1848A	SSD-206	234	28	SCR
TA1211	2N1849A	SSD-206	234	28	SCR
TA1212	2N1850A	SSD-206	234	28	SCR
TA1214	1N1187A	SSD-206	291	38	RECT
TA1215	1N1188A	SSD-206	291	38	RECT
TA1216	1N1189A	SSD-206	291	38	RECT
TA1217	1N1190A	SSD-206	291	38	RECT
TA1222	2N3228	SSD-206	144	114	SCR
TA1225	2N3525	SSD-206	144	114	SCR
TA1863	2N1491	SSD-205	24	10	RF
TA1883	2N1492	SSD-205	24	10	RF
TA1910A	2N697	SSD-204	493	16	PWR
TA1951	2N1493	SSD-205	24	10	RF
TA1986	2N699	SSD-204	495	22	PWR
TA2053	2N1613	SSD-204	498	106	PWR
TA2053A	2N1711	SSD-204	503	26	PWR
TA2053B	2N2102	SSD-204	498	106	PWR
TA2192A	2N2270	SSD-204	513	24	PWR
TA2275	2N2895	SSD-204	517	143	PWR
TA2276	2N2896	SSD-204	517	143	PWR
TA2277	2N2897	SSD-204	517	143	PWR
TA2307	2N3375	SSD-205	52	386	RF
TA2311	2N2876	SSD-205	28	32	RF
TA2333	2N2857	SSD-205	33	61	RF
TA2358	2N918	SSD-205	20	83	RF
TA2358A	2N3600	SSD-205	20	83	RF
TA2363	2N3839	SSD-205	69	229	RF
TA2388	2N3229	SSD-205	45	50	RF
TA2402A	2N3054	SSD-204	45	527	PWR
TA2403A	2N3055	SSD-204	102	524	PWR
TA2442	2N3870	SSD-206	218	578	SCR
TA2444	2N3871	SSD-206	218	578	SCR
TA2447	2N3872	SSD-206	218	578	SCR
TA2458	2N3439	SSD-204	286	64	PWR
TA2462	2N3118	SSD-205	37	42	RF
TA2463	2N3119	SSD-205	41	44	RF
TA2468A	2N3442	SSD-204	133	528	PWR
TA2469A	2N3441	SSD-204	69	529	PWR
TA2470	2N3440	SSD-204	286	64	PWR
TA2492	2N3263	SSD-204	475	54	PWR
TA2493	2N3264	SSD-204	475	54	PWR
TA2494	2N3265	SSD-204	475	54	PWR
TA2495	2N3266	SSD-204	475	54	PWR
TA2501	2N3[illegible]62	SSD-205	48	56	RF
TA2509	2N3[illegible]78	SSD-204	443	299	PWR
TA2509A	2N3879	SSD-204	443	299	PWR
TA2510	2N3583	SSD-204	304	138	PWR
TA2511	2N3584	SSD-204	304	138	PWR
TA2512	2N3585	SSD-204	304	138	PWR
TA2515	2N690	SSD-206	225	96	SCR
TA2544	2N3772	SSD-204	141	525	PWR
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TA2581	1N1344B	SSD-206	281	58	RECT
TA2582	1N1345B	SSD-206	281	58	RECT
TA2583	1N1346B	SSD-206	281	58	RECT
TA2584	1N1347B	SSD-206	281	58	RECT
TA2585	1N1348B	SSD-206	281	58	RECT
TA2586	1N1341RB	SSD-206	281	58	RECT
TA2587	1N1342RB	SSD-206	281	58	RECT
TA2588	1N1344RB	SSD-206	281	58	RECT
TA2589	1N1345RB	SSD-206	281	58	RECT
TA2590	1N1346RB	SSD-206	281	58	RECT
TA2591	1N1347RB	SSD-206	281	58	RECT
TA2592	1N1348RB	SSD-206	281	58	RECT
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TA2598	2N3669	SSD-206	203	116	SCR
TA2600	40282	SSD-205	279	68	RF
TA2606	2N3478	SSD-205	60	77	RF
TA2616	2N3632	SSD-205	52	386	RF
TA2617	2N3529	SSD-206	144	114	SCR
TA2618	2N3670	SSD-206	203	116	SCR
TA2619	40280	SSD-205	275	301	RF
TA2620	40281	SSD-205	279	68	RF
TA2621	2N3668	SSD-206	203	116	SCR
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TA2645A	2N3773	SSD-204	149	526	PWR
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TA2653	S3700B	SSD-206	172	306	SCR
TA2654	S3700D	SSD-206	172	306	SCR
TA2655	S3700M	SSD-206	172	306	SCR
TA2657	40341	SSD-205	287	74	RF
TA2657A	40340	SSD-205	287	74	RF
TA2658	2N3866	SSD-205	73	80	RF
TA2669	2N5039	SSD-204	461	698	PWR
TA2669A	2N5038	SSD-204	461	698	PWR
TA2670	2N4037	SSD-204	410	216	PWR
TA2670A	2N4314	SSD-204	410	216	PWR
TA2675	2N5016	SSD-205	96	255	RF
TA2676	T2700B	SSD-206	62	351	TRI
TA2685	T2700D	SSD-206	62	351	TRI
TA2692	2N3733	SSD-205	64	72	RF
TA2694	2N3896	SSD-206	218	578	SCR

Developmental Number-to-Commercial Number Cross-Reference Index

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TA2696	2N3898	SSD-206	218	578	SCR
TA2703A	40349	SSD-204	26	88	PWR
TA2705	2N3873	SSD-206	218	578	SCR
TA2707	2N3899	SSD-206	218	578	SCR
TA2710	41024	SSD-205	379	658	RF
TA2714	2N4012	SSD-205	77	90	RF
TA2733	40319	SSD-204	654	78	PWR
TA2733A	40362	SSD-204	654	78	PWR
TA2758	2N6093	SSD-205	216	484	RF
TA2761	40608	SSD-205	291	356	RF
TA2765	2N5239	SSD-204	373	321	PWR
TA2765A	2N5240	SSD-204	373	321	PWR
TA2773	2N4101	SSD-206	144	114	SCR
TA2774	2N4102	SSD-206	144	114	SCR
TA2775	2N4103	SSD-206	203	116	SCR
TA2791	2N5102	SSD-205	113	279	RF
TA2792	2N4933	SSD-205	92	249	RF
TA2793	2N5070	SSD-205	100	268	RF
TA2800	2N5109	SSD-205	118	281	RF
TA2808	2N4348	SSD-204	149	526	PWR
TA2809	2N4347	SSD-204	133	528	PWR
TA2819	2N5415	SSD-204	292	336	PWR
TA2819A	2N5416	SSD-204	292	336	PWR
TA2827	2N5071	SSD-205	105	269	RF
TA2828	2N4932	SSD-205	92	249	RF
TA2836	2N5441	SSD-206	55	593	TRI
TA2837	2N5442	SSD-206	55	593	TRI
TA2838	2N5444	SSD-206	55	593	TRI
TA2839	2N5445	SSD-206	55	593	TRI
TA2840	3N128	SSD-201	634	309	MOS/FET
TA2845	1N5214	SSD-206	270	245	RECT
TA2845A	1N5213	SSD-206	270	245	RECT
TA2845B	1N5212	SSD-206	270	245	RECT
TA2845C	1N5211	SSD-206	270	245	RECT
TA2871	2N4240	SSD-204	304	138	PWR
TA2875	2N4440	SSD-205	87	217	RF
TA2892	T2300A	SSD-206	33	470	TRI
TA2829A	T2302A	SSD-206	33	470	TRI
TA2893	T2300B	SSD-206	33	470	TRI
TA2893A	T2302B	SSD-206	33	470	TRI
TA2894	T2300D	SSD-206	33	470	TRI
TA2894A	T2302D	SSD-206	33	470	TRI
TA2911	2N5294	SSD-204	61	322	PWR
TA5032	CA3000	SSD-201	288	121	LIC
TA5033	CA3001	SSD-201	294	122	LIC
TA5035	CA3002	SSD-201	256	123	LIC
TA5037	CA3004	SSD-201	300	124	LIC
TA5112	CA3005	SSD-201	306	125	LIC
TA5112A	CA3006	SSD-201	306	125	LIC
TA5115B	CA3007	SSD-201	313	126	LIC
TA5124	CA3008	SSD-201	80	316	LIC
TA5158	CA3015	SSD-201	80	316	LIC
TA5164	CD2150	SSD-201	409	308	LIC
TA5165	CD2151	SSD-201	409	308	LIC
TA5166	CD2152	SSD-201	409	308	LIC
TA5180	CA3010	SSD-201	80	316	LIC
TA5183	CA3033	SSD-201	61	360	LIC
TA5183A	CA3033A	SSD-201	61	360	LIC
TA5213	CA3011	SSD-201	262	128	LIC
TA5214	CA3012	SSD-201	262	128	LIC
TA5218	CA3023	SSD-201	276	243	LIC
TA5219	CA3021	SSD-201	276	243	LIC
TA5220	CA3020	SSD-201	268	339	LIC
TA5222	CA3018	SSD-201	160	338	LIC
TA5222A	CA3018A	SSD-201	160	338	LIC
TA5225	CA3019	SSD-201	118	236	LIC
TA5234	CA3013	SSD-201	471	129	LIC
TA5235	CA3014	SSD-201	471	129	LIC
TA5236	CA3022	SSD-201	276	243	LIC
TA5253	CA3016	SSD-201	80	316	LIC
TA5254	CA3030	SSD-201	80	316	LIC
TA5261	CD2153	SSD-201	409	308	LIC
TA5277	CA3001	SSD-201	294	122	LIC
TA5278	CA3029	SSD-201	80	316	LIC
TA5282	CA3004	SSD-201	300	124	LIC
TA5315	CA3043	SSD-201	466	331	LIC
TA5316	CA3041	SSD-201	498	318	LIC
TA5317A	CA3042	SSD-201	506	319	LIC
TA5327C	CA3040	SSD-201	282	363	LIC

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TA5333	CA3036	SSD-201	158	275	LIC
TA5334	CA3035	SSD-201	243	274	LIC
TA5334	CA3035V1	SSD-201	243	274	LIC
TA5345	CA3028A	SSD-201	318	382	LIC
TA5345A	CA3028B	SSD-201	318	382	LIC
TA5346	CA3015A	SSD-201	89	310	LIC
TA5347	CA3010A	SSD-201	89	310	LIC
TA5348	CA3030A	SSD-201	89	310	LIC
TA5349	CA3029A	SSD-201	89	310	LIC
TA5350	CA3016A	SSD-201	89	310	LIC
TA5351	CA3008A	SSD-201	89	310	LIC
TA5360	CA3044	SSD-201	484	340	LIC
TA5361B	CD4000A	SSD-203	30	479	COS/MOS
TA5369	CA3040	SSD-201	282	363	LIC
TA5371B	CA3062	SSD-201	367	421	LIC
TA5385CV	CD4024AK	SSD-203	120	503	COS/MOS
TA5401	CA3038	SSD-201	80	316	LIC
TA5401	CA3038A	SSD-201	89	310	LIC
TA5402	CA3037	SSD-201	80	316	LIC
TA5402	CA3037A	SSD-201	89	310	LIC
TA5455B	CD4001A	SSD-203	30	479	COS/MOS
TA5456B	CD4002A	SSD-203	30	479	COS/MOS
TA5457	CA3045	SSD-201	177	341	LIC
TA5458	CA3046	SSD-201	177	341	LIC
TA5460AV	CD4016AK	SSD-203	84	479	COS/MOS
TA5507	CA3050	SSD-201	329	361	LIC
TA5513	CA3026	SSD-201	226	388	LIC
TA5516	CA3039	SSD-201	122	343	LIC
TA5517C	CA3064	SSD-201	490	396	LIC
TA5519V	CD4008AK	SSD-203	49	479	COS/MOS
TA5523A	CA3048	SSD-201	247	377	LIC
TA5537	CA3049T	SSD-201	234	611	LIC
TA5551	CD4000AK	SSD-203	30	479	COS/MOS
TA5553	CD4007AK	SSD-203	43	479	COS/MOS
TA5554	CD4001AK	SSD-203	30	479	COS/MOS
TA5555	CD4002AK	SSD-203	30	479	COS/MOS
TA5556B	CD4006AK	SSD-203	37	479	COS/MOS
TA5561	CA3047A	SSD-201	61	360	LIC
TA5562	CA3047	SSD-201	61	360	LIC
TA5578V	CD4014AK	SSD-203	74	479	COS/MOS
TA5579V	CD4015AK	SSD-203	79	479	COS/MOS
TA5580V	CD4018AK	SSD-203	95	479	COS/MOS
TA5615A	CA3059	SSD-201	338	490	LIC
TA5625A	CA3066	SSD-201	533	466	LIC
TA5628C	CA3089E	SSD-201	455	561	LIC
TA5634	CD2154	SSD-201	421	402	LIC
TA5645	CA3060E	SSD-201	38	537	LIC
TA5649A	CA3070	SSD-201	549	468	LIC
TA5652V	CD4019AK	SSD-203	100	479	COS/MOS
TA5655	CA3051	SSD-201	329	361	LIC
TA5660V	CD4009AK	SSD-203	54	479	COS/MOS
TA5668V	CD4010AK	SSD-203	54	479	COS/MOS
TA5672	CA3052	SSD-201	432	387	LIC
TA5675V	CD4013AK	SSD-203	68	479	COS/MOS
TA5677V	CD4044AK	SSD-203	214	590	COS/MOS
TA5681V	CD4011AK	SSD-203	61	479	COS/MOS
TA5682V	CD4012AK	SSD-203	61	479	COS/MOS
TA5683V	CD4021AK	SSD-203	110	479	COS/MOS
TA5684V	CD4017AK	SSD-203	90	479	COS/MOS
TA5690X	CD2501E	SSD-201	403	392	LIC
TA5702B	CA3071	SSD-201	549	468	LIC
TA5716V	CD4057AK	SSD-203	272	635	COS/MOS
TA5716W	CD4057AD	SSD-203	272	635	COS/MOS
TA5718	CA3054	SSD-201	226	388	LIC
TA5721X	CD2500E	SSD-201	403	392	LIC
TA5733	CA3053	SSD-201	318	382	LIC
TA5752	CA3067	SSD-201	533	466	LIC
TA5757	CA3076	SSD-201	479	430	LIC
TA5758B	CA3085	SSD-201	375	491	LIC
TA5776V	CD4020AK	SSD-203	105	479	COS/MOS
TA5785X	CD2503E	SSD-201	403	392	LIC
TA5786X	CD2502E	SSD-201	403	392	LIC
TA5790	CA3060D	SSD-201	38	537	LIC
TA5795	CA3058	SSD-201	338	490	LIC
TA5797	CA741T	SSD-201	74	531	LIC
TA5799A	CA3084	SSD-201	134	482	LIC
TA5807	CA3078T	SSD-201	52	535	LIC
TA5814	CA3065	SSD-201	514	412	LIC
TA5816	CA3080	SSD-201	30	475	LIC
TA5820	CA3541D	SSD-201	395	536	LIC

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TA5842	CA3088E	SSD-201	446	560	LIC
TA5855A	CA3091D	SSD-201	383	534	LIC
TA5858	CA3081	SSD-201	126	480	LIC
TA5866	CA3075	SSD-201	462	429	LIC
TA5867V	CD4023AK	SSD-203	61	479	COS/MOS
TA5867W	CD4023AD	SSD-203	61	479	COS/MOS
TA5867X	CD4023AE	SSD-203	61	479	COS/MOS
TA5872V	CD4027AK	SSD-203	135	503	COS/MOS
TA5873V	CD4028AK	SSD-203	141	503	COS/MOS
TA5876W	CD4035AD	SSD-203	177	568	COS/MOS
TA5878W	CD4034AD	SSD-203	169	575	COS/MOS
TA5884AV	CD4022AK	SSD-203	115	479	COS/MOS
TA5884W	CD4022AD	SSD-203	115	479	COS/MOS
TA5884AX	CD4022AE	SSD-203	115	479	COS/MOS
TA5897X	CD2501E	SSD-201	698	392	LIC
TA5898X	CD2503E	SSD-201	698	392	LIC
TA5899X	CD2500E	SSD-201	698	392	LIC
TA5900X	CD2502E	SSD-201	698	392	LIC
TA5912B	CA3072	SSD-201	549	468	LIC
TA5914C	CA3068	SSD-201	525	467	LIC
TA5920V	CD4025AK	SSD-203	30	479	COS/MOS
TA5920W	CD4025AD	SSD-203	30	479	COS/MOS
TA5920X	CD4025AE	SSD-203	30	479	COS/MOS
TA5925V	CD4029AK	SSD-203	146	503	COS/MOS
TA5925W	CD4029AD	SSD-203	146	503	COS/MOS
TA5925X	CD4029AE	SSD-203	146	503	COS/MOS
TA5926V	CD4036AK	SSD-203	184	613	COS/MOS
TA5926W	CD4036AD	SSD-203	184	613	COS/MOS
TA5932	CA3090Q	SSD-201	440	502	LIC
TA5940V	CD4030AK	SSD-203	153	503	COS/MOS
TA5940W	CD4030AD	SSD-203	153	503	COS/MOS
TA5940X	CD4030AE	SSD-203	153	503	COS/MOS
TA5951V	CD4038AK	SSD-203	164	503	COS/MOS
TA5951W	CD4038AD	SSD-203	164	503	COS/MOS
TA5951X	CD4038AE	SSD-203	164	503	COS/MOS
TA5957	CA3018L	SSD-201	605	515	LIC
TA5958	CA3039L	SSD-201	605	515	LIC
TA5959	CA3045L	SSD-201	605	515	LIC
TA5960	CA3054L	SSD-201	605	515	LIC
TA5963V	CD4032AK	SSD-203	164	503	COS/MOS
TA5963W	CD4032AD	SSD-203	164	503	COS/MOS
TA5963X	CD4032AE	SSD-203	164	503	COS/MOS
TA5964	CA3015L	SSD-201	605	515	LIC
TA5975	CA3028AL	SSD-201	605	515	LIC
TA5978	CA3084L	SSD-201	605	515	LIC
TA5979	CA741L	SSD-201	605	515	LIC
TA5989	CD4031AD	SSD-203	158	569	COS/MOS
TA5998	CA3083	SSD-201	130	481	LIC
TA5999W	CD4037AD	SSD-203	191	576	COS/MOS
TA6007W	CD4051AD	SSD-203	258	Prel.	COS/MOS
TA6010V	CD4047AK	SSD-203	233	623	COS/MOS
TA6010W	CD4047AD	SSD-203	233	623	COS/MOS
TA6010X	CD4047AE	SSD-203	233	623	COS/MOS
TA6011	CD4042AD	SSD-203	210	589	COS/MOS
TA6014	CA3068	SSD-201	525	467	LIC
TA6018V	CD4026AK	SSD-203	126	503	COS/MOS
TA6018W	CD4026AD	SSD-203	126	503	COS/MOS
TA6018X	CD4026AE	SSD-203	126	503	COS/MOS
TA6029	CA741CT	SSD-201	74	531	LIC
TA6031V	CD4041AK	SSD-203	203	572	COS/MOS
TA6031W	CD4041AD	SSD-203	203	572	COS/MOS
TA6031X	CD4041AE	SSD-203	203	572	COS/MOS
TA6033	CA3082	SSD-201	126	480	LIC
TA6037	CA748CT	SSD-201	74	531	LIC
TA5037A	CA748T	SSD-201	74	531	LIC
TA6044	CA3086	SSD-201	183	483	LIC
TA6051	CA3079	SSD-201	338	490	LIC
TA6062W	CD4045AD	SSD-203	220	614	COS/MOS
TA6062X	CD4045AE	SSD-203	220	614	COS/MOS
TA6065V	CD4040AK	SSD-203	197	624	COS/MOS
TA6065W	CD4040AD	SSD-203	197	624	COS/MOS
TA6065X	CD4040AE	SSD-203	197	624	COS/MOS
TA6080V	CD4043AK	SSD-203	214	590	COS/MOS
TA6080W	CD4043AD	SSD-203	214	590	COS/MOS
TA6080X	CD4043AE	SSD-203	214	590	COS/MOS
TA6081V	CD4044AK	SSD-203	214	590	COS/MOS
TA6081W	CD4044AD	SSD-203	214	590	COS/MOS
TA6081X	CD4044AE	SSD-203	214	590	COS/MOS
TA6084	CA3146AE	SSD-201	166	532	LIC
TA6091	CA3118AT	SSD-201	166	532	LIC
TA6094	CA3183AE	SSD-201	166	532	LIC
TA6111	CA1458T	SSD-201	74	531	LIC
TA6111A	CA1558T	SSD-201	74	531	LIC
TA6116V	CD4046AK	SSD-203	226	637	COS/MOS
TA6116W	CD4046AD	SSD-203	226	637	COS/MOS
TA6116X	CD4046AE	SSD-203	226	637	COS/MOS
TA6119	CA3093E	SSD-201	152	533	LIC
TA6122C	CA3100T	SSD-201	98	625	LIC
TA6144B	CA3121E	SSD-201	567	688	LIC
TA6145V	CD4039AK	SSD-203	184	613	COS/MOS
TA6145W	CD4039AD	SSD-203	184	613	COS/MOS
TA6145X	CD4039AE	SSD-203	184	613	COS/MOS
TA6153W	CD4052AD	SSD-203	258	Prel.	COS/MOS
TA6154W	CD4053AD	SSD-203	258	Prel.	COS/MOS
TA6155D	CA3123E	SSD-201	450	631	LIC
TA6157	CA747CE	SSD-201	74	531	LIC
TA6157A	CA747E	SSD-201	74	531	LIC
TA6164	CA3094T	SSD-201	346	598	LIC
TA6165A	CA3094AT	SSD-201	346	598	LIC
TA6181	CA3146E	SSD-201	166	532	LIC
TA6182	CA3118T	SSD-201	166	532	LIC
TA6183	CA3183E	SSD-201	166	532	LIC
TA6189	CA3099E	SSD-201	359	620	LIC
TA6220	CA2111AE	SSD-201	520	612	LIC
TA6228	CA3102E	SSD-201	234	611	LIC
TA6237V	CD4054AK	SSD-203	266	634	COS/MOS
TA6237W	CD4054AD	SSD-203	266	634	COS/MOS
TA6237X	CD4054AE	SSD-203	266	634	COS/MOS
TA6238V	CD4055AK	SSD-203	266	634	COS/MOS
TA6238W	CD4055AD	SSD-203	266	634	COS/MOS
TA6238X	CD4055AE	SSD-203	266	634	COS/MOS
TA6243X	CA3120E	SSD-201	581	691	LIC
TA6246V	CD4049AK	SSD-203	251	599	COS/MOS
TA6246W	CD4049AD	SSD-203	251	599	COS/MOS
TA6246X	CD4049AE	SSD-203	251	599	COS/MOS
TA6250V	CD4048AK	SSD-203	244	636	COS/MOS
TA6250W	CD4048AD	SSD-203	244	636	COS/MOS
TA6250X	CD4048AE	SSD-203	244	636	COS/MOS
TA6251V	CD4056AK	SSD-203	266	634	COS/MOS
TA6251W	CD4056AD	SSD-203	266	634	COS/MOS
TA6251X	CD4056AE	SSD-203	266	634	COS/MOS
TA6265V	CD4050AK	SSD-203	251	599	COS/MOS
TA6265W	CD4050AD	SSD-203	251	599	COS/MOS
TA6265X	CD4050AE	SSD-203	251	599	COS/MOS
TA6269X	CA3095E	SSD-201	189	591	LIC
TA6270X	CA3096E	SSD-201	141	595	LIC
TA6270AX	CA3096AE	SSD-201	141	595	LIC
TA6281X	CA3097E	SSD-201	199	633	LIC
TA6281X	CA3097E	SSD-201	199	633	LIC
TA6289X	CA747CE	SSD-201	74	531	LIC
TA6289AX	CA747E	SSD-201	74	531	LIC
TA6306	CA3401E	SSD-201	113	630	LIC
TA6309	CA3049L	SSD-201	605	515	LIC
TA6314T	CA1458T	SSD-201	74	531	LIC
TA6314T	CA1558T	SSD-201	74	531	LIC
TA6319	CA3126Q	SSD-201	565	Prel.	LIC
TA6330T	CA3094AT	SSD-201	346	598	LIC
TA6368X	CA3600E	SSD-201	213	619	LIC
TA6379X	CA3072	SSD-201	549	468	LIC
TA6389T	CA3080	SSD-201	30	475	LIC
TA6391W	CD4066AD	SSD-203	303	Prel.	COS/MOS
TA7003	2N5470	SSD-205	140	350	RF
TA7005	2N6249	SSD-204	385	523	PWR
TA7006	2N6250	SSD-204	385	523	PWR
TA7007	2N6251	SSD-204	385	523	PWR
TA7016	2N5575	SSD-204	162	359	PWR
TA7017	2N5578	SSD-204	162	359	PWR
TA7032	3N138	SSD-201	639	283	MOS/FET
TA7047	2N4427	SSD-205	81	228	RF
TA7048	1N5218	SSD-206	270	245	RECT
TA7048A	1N5217	SSD-206	270	245	RECT
TA7048B	1N5216	SSD-206	270	245	RECT
TA7048C	1N5215	SSD-206	270	245	RECT
TA7078	40606	SSD-207	168	600	RF
TA7079	40577	SSD-207	148	297	RF
TA7080	40578	SSD-207	155	298	RF
TA7090	JAN2N3866	SSD-207	81	–	RF
TA7121	2N5320	SSD-204	429	325	PWR
TA7122	2N5321	SSD-204	429	325	PWR
TA7124	2N5322	SSD-204	429	325	PWR

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TA7125	2N5323	SSD-204	429	325	PWR
TA7130	2N5804	SSD-204	379	407	PWR
TA7130A	2N5805	SSD-204	379	407	PWR
TA7134	2N6177	SSD-204	278	508	PWR
TA7137	2N5296	SSD-204	61	322	PWR
TA7146	2N5090	SSD-205	109	270	RF
TA7149	40600	SSD-201	712	333	MOS/FET
TA7150	40603	SSD-201	720	334	MOS/FET
TA7151	40604	SSD-201	720	334	MOS/FET
TA7155	2N5293	SSD-204	61	322	PWR
TA7156	2N5295	SSD-204	61	322	PWR
TA7189	40602	SSD-201	712	333	MOS/FET
TA7205	2N5921	SSD-205	181	427	RF
TA7238	2N5262	SSD-204	423	313	PWR
TA7244	3N139	SSD-201	643	284	MOS/FET
TA7262	40601	SSD-201	712	333	MOS/FET
TA7264	2N5954	SSD-204	170	675	PWR
TA7265	2N5955	SSD-204	170	675	PWR
TA7266	2N5956	SSD-204	170	675	PWR
TA7270	2N5781	SSD-204	34	413	PWR
TA7271	2N5782	SSD-204	34	413	PWR
TA7272	2N5783	SSD-204	34	413	PWR
TA7274	3N141	SSD-201	667	285	MOS/FET
TA7275	3N143	SSD-201	634	309	MOS/FET
TA7279	2N6248	SSD-204	217	677	PWR
TA7280	2N6247	SSD-204	217	677	PWR
TA7281	2N6246	SSD-204	217	677	PWR
TA7285	2N5202	SSD-204	443	299	PWR
TA7289	2N5784	SSD-204	34	413	PWR
TA7290	2N5785	SSD-204	34	413	PWR
TA7291	2N5786	SSD-204	34	413	PWR
TA7303	2N5180	SSD-205	130	289	RF
TA7306	3N142	SSD-201	648	286	MOS/FET
TA7311	2N5496	SSD-204	90	353	PWR
TA7312	2N5497	SSD-204	90	353	PWR
TA7313	2N5494	SSD-204	90	353	PWR
TA7314	2N5495	SSD-204	90	353	PWR
TA7315	2N5492	SSD-204	90	353	PWR
TA7316	2N5493	SSD-204	90	353	PWR
TA7317	2N5490	SSD-204	90	353	PWR
TA7318	2N5491	SSD-204	90	353	PWR
TA7319	2N5179	SSD-204	124	288	RF
TA7322	2N5189	SSD-204	418	296	PWR
TA7323	2N5671	SSD-204	481	383	PWR
TA7323A	2N5672	SSD-204	481	383	PWR
TA7327	JANTX2N3866	SSD-207	81	–	RF
TA7328	JANTX2N3553	SSD-207	80	–	RF
TA7329	JANTX2N3375	SSD-207	80	–	RF
TA7337	2N6032	SSD-204	487	462	PWR
TA7337A	2N6033	SSD-204	487	462	PWR
TA7352	3N153	SSD-201	659	320	MOS/FET
TA7353	3N152	SSD-201	654	314	MOS/FET
TA7354	JAN2N4440	SSD-207	80	–	RF
TA7355	JANTX2N4440	SSD-207	80	–	RF
TA7358	JANTX2N5071	SSD-207	81	–	RF
TA7360	JAN2N5071	SSD-207	81	–	RF
TA7361	40605	SSD-205	318	389	RF
TA7362	2N5297	SSD-204	61	322	PWR
TA7363	2N5298	SSD-204	61	322	PWR
TA7364	T2800B	SSD-206	69	364	TRI
TA7365	T2800D	SSD-206	69	364	TRI
TA7367	2N5918	SSD-205	164	448	RF
TA7374	3N159	SSD-201	675	326	MOS/FET
TA7375	3N154	SSD-201	662	335	MOS/FET
TA7381	2N6098	SSD-204	121	485	PWR
TA7382	2N6099	SSD-204	121	485	PWR
TA7383	2N6100	SSD-204	121	485	PWR
TA7384	2N6101	SSD-204	121	485	PWR
TA8385	2N6102	SSD-204	121	485	PWR
TA7386	2N6103	SSD-204	121	485	PWR
TA7399	40673	SSD-201	745	381	MOS/FET
TA7401	D3202U	SSD-206	350	577	DIAC
TA7403	40836	SSD-205	298	497	RF
TA7404	S2800B	SSD-206	166	501	SCR
TA7405	S2800D	SSD-206	166	501	SCR
TA7408	2N5914	SSD-205	152	424	RF
TA7409	2N5915	SSD-205	152	424	RF
TA7410	2N6212	SSD-204	312	507	PWR
TA7411	2N5916	SSD-205	158	425	RF
TA7420	2N5840	SSD-204	356	410	PWR
TA7426	2N5443	SSD-206	55	593	TRI
TA7427	2N5446	SSD-206	55	593	TRI
TA7428	2N5567	SSD-206	92	457	TRI
TA7429	2N5568	SSD-206	92	457	TRI
TA7430	2N5571	SSD-206	85	458	TRI
TA7431	2N5572	SSD-206	85	458	TRI
TA7434	S2600B	SSD-206	156	496	SCR
TA7435	S2600D	SSD-206	156	496	SCR
TA7441	T6401B	SSD-206	107	459	TRI
TA7442	T6401D	SSD-206	107	459	TRI
TA7452	S3705M	SSD-206	187	354	SCR
TA7453	S3706M	SSD-206	187	354	SCR
TA7454	D2601EF	SSD-206	303	354	RECT
TA7455	D2601DF	SSD-206	303	354	RECT
TA7456	D2600EF	SSD-206	303	354	RECT
TA7461	T6411B	SSD-206	107	459	TRI
TA7462	T6411D	SSD-206	107	459	TRI
TA7463	S2620B	SSD-206	156	496	SCR
TA7464	S2620D	SSD-206	156	496	SCR
TA7465	S2610B	SSD-206	156	496	SCR
TA7466	S2610D	SSD-206	156	496	SCR
TA7467	T4101M	SSD-206	92	457	TRI
TA7468	T4100M	SSD-206	85	458	TRI
TA7477	2N5913	SSD-205	146	423	RF
TA7479	2N5569	SSD-206	92	457	TRI
TA7480	2N5570	SSD-206	92	457	TRI
TA7481	T4111M	SSD-206	92	457	TRI
TA7482	2N5573	SSD-206	85	458	TRI
TA7483	2N5574	SSD-206	85	458	TRI
TA7484	T4110M	SSD-206	85	458	TRI
TA7487	2N5920	SSD-205	175	440	RF
TA7500	2N5754	SSD-206	28	414	TRI
TA7501	2N5755	SSD-206	28	414	TRI
TA7502	2N5756	SSD-206	28	414	TRI
TA7503	2N5757	SSD-206	28	414	TRI
TA7504	T6420B	SSD-206	55	593	TRI
TA7505	T6420D	SSD-206	55	593	TRI
TA7506	T6420M	SSD-206	55	593	TRI
TA7507	S6420B	SSD-206	218	578	SCR
TA7508	S6420D	SSD-206	218	578	SCR
TA7509	S6420M	SSD-206	218	578	SCR
TA7513	2N5838	SSD-204	356	410	PWR
TA7514	40964	SSD-205	351	581	RF
TA7518	T2800M	SSD-206	69	364	TRI
TA7530	2N5839	SSD-204	356	410	PWR
TA7532	2N5919A	SSD-205	169	505	RF
TA7534	2N6354	SSD-204	469	582	PWR
TA7542	S3800MF	SSD-206	199	639	ITR
TA7543	S3800M	SSD-206	199	639	ITR
TA7543	S2060Q	SSD-206	138	654	SCR
TA7545	S2060Y	SSD-206	138	654	SCR
TA7546	S2060F	SSD-206	138	654	SCR
TA7547	T4121B	SSD-206	92	457	TRI
TA7548	T4121D	SSD-206	92	457	TRI
TA7549	T4121M	SSD-206	92	457	TRI
TA7550	T4120B	SSD-206	85	458	TRI
TA7551	T4120D	SSD-206	85	458	TRI
TA7552	T4120M	SSD-206	85	458	TRI
TA7553	S7430M	SSD-206	238	408	SCR
TA7554	2N6178	SSD-204	435	562	PWR
TA7555	2N6179	SSD-204	435	562	PWR
TA7556	2N6180	SSD-204	435	562	PWR
TA7557	2N6181	SSD-204	435	562	PWR
TA7563	S6200B	SSD-206	210	418	SCR
TA7564	S6200D	SSD-206	210	418	SCR
TA7565	S6200M	SSD-206	210	418	SCR
TA7570	S6210B	SSD-206	210	418	SCR
TA7571	S6210D	SSD-206	210	418	SCR
TA7579	T2313A	SSD-206	28	414	TRI
TA7580	T2313B	SSD-206	28	414	TRI
TA7581	T2313D	SSD-206	28	414	TRI
TA7582	2N5757	SSD-206	28	414	TRI
TA7582	T2313M	SSD-206	28	414	TRI
TA7583	T6401M	SSD-206	107	459	TRI
TA7584	T6411M	SSD-206	107	459	TRI
TA7588	40965	SSD-205	351	581	RF
TA7589	2N5994	SSD-205	199	453	RF
TA7590	2N3650	SSD-206	238	408	SCR
TA7591	2N3651	SSD-206	238	408	SCR
TA7592	2N3652	SSD-206	238	408	SCR

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TA7600	S6220D	SSD-206	210	418	SCR
TA7601	S6220M	SSD-206	210	418	SCR
TA7602	T6421B	SSD-206	107	459	TRI
TA7603	T6421D	SSD-206	107	459	TRI
TA7604	T6421M	SSD-206	107	459	TRI
TA7614	T4104B	SSD-206	99	443	TRI
TA7615	T4104D	SSD-206	99	443	TRI
TA7616	T4114B	SSD-206	99	443	TRI
TA7617	T4114D	SSD-206	99	443	TRI
TA7618	T4103B	SSD-206	99	443	TRI
TA7619	T4103D	SSD-206	99	443	TRI
TA7620	T4113B	SSD-206	99	443	TRI
TA7621	T4113D	SSD-206	99	443	TRI
TA7626A	HC2000H	SSD-204	555	566	HYB
TA7642	T4105B	SSD-206	99	443	TRI
TA7643	T4105D	SSD-206	99	443	TRI
TA7644	T4115B	SSD-206	99	443	TRI
TA7645	T4115D	SSD-206	99	443	TRI
TA7646	T6405B	SSD-206	114	487	TRI
TA7647	T6405D	SSD-206	114	487	TRI
TA7648	T6415B	SSD-206	114	487	TRI
TA7649	T6415D	SSD-206	114	487	TRI
TA7650	T6405B	SSD-206	114	487	TRI
TA7651	T6405D	SSD-206	114	487	TRI
TA7652	T6414B	SSD-206	114	487	TRI
TA7653	T6414D	SSD-206	114	487	TRI
TA7654	T2304B	SSD-206	41	441	TRI
TA7655	T2304D	SSD-206	41	441	TRI
TA7656	T2305B	SSD-206	41	441	TRI
TA7657	T2305D	SSD-206	41	441	TRI
TA7669	3N187	SSD-201	690	436	MOS/FET
TA7670	S6420A	SSD-206	218	578	SCR
TA7673	2N6078	SSD-204	318	492	PWR
TA7679	40837	SSD-205	298	497	RF
TA7680	40941	SSD-205	342	554	RF
TA7684	3N200	SSD-201	698	437	MOS/FET
TA7686	40893	SSD-205	304	514	RF
TA7706	2N6105	SSD-205	221	504	RF
TA7707	2N6104	SSD-205	221	504	RF
TA7719	2N6211	SSD-204	312	507	PWR
TA7739	2N6175	SSD-204	278	508	PWR
TA7740	2N6176	SSD-204	278	508	PWR
TA7741	2N6107	SSD-204	177	676	PWR
TA7742	2N6109	SSD-204	177	676	PWR
TA7743	SSD-204	SSD-204	177	676	PWR
TA7752	T8430B	SSD-206	130	549	TRI
TA7753	T8430D	SSD-206	130	549	TRI
TA7754	T8430M	SSD-206	130	549	TRI
TA7755	T8440B	SSD-206	130	459	TRI
TA7756	T8440D	SSD-206	130	549	TRI
TA7757	T8440M	SSD-206	130	549	TRI
TA7782	2N6292	SSD-204	177	676	PWR
TA7783	2N6290	SSD-204	177	676	PWR
TA7784	2N6288	SSD-204	177	676	PWR
TA7802	D1201B	SSD-206	278	495	RECT
TA7803	D1201D	SSD-206	278	495	RECT
TA7804	D1201M	SSD-206	278	495	RECT
TA7805	D1201N	SSD-206	278	495	RECT
TA7806	D1201P	SSD-206	278	495	RECT
TA7821	S6400N	SSD-206	218	578	SCR
TA7823	S6410N	SSD-206	218	578	SCR
TA7825	S6420N	SSD-206	218	578	SCR
TA7852	2N5917	SSD-205	158	425	RF
TA7920	2N5992	SSD-205	189	451	RF
TA7921	2N5993	SSD-205	194	452	RF
TA7922	2N5995	SSD-205	205	454	RF
TA7923	2N5996	SSD-205	210	455	RF
TA7936	40819	SSD-201	704	463	MOS/FET
TA7937	T8450B	SSD-206	130	549	TRI
TA7938	T8450D	SSD-206	130	549	TRI
TA7939	T8450M	SSD-206	130	549	TRI
TA7941	40934	SSD-205	329	550	RF
TA7943	40909	SSD-205	321	547	RF
TA7982	40940	SSD-205	337	553	RF
TA7984	D2540A	SSD-206	345	580	RECT
TA7985	D2540B	SSD-206	345	580	RECT
TA7986	D2540D	SSD-206	345	580	RECT
TA7987	D2540M	SSD-206	345	580	RECT
TA7988	S2060A	SSD-206	138	654	SCR
TA7989	S2060B	SSD-206	138	654	SCR
TA7990	S2060C	SSD-206	138	654	SCR
TA7991	S2060D	SSD-206	138	654	SCR
TA7993	2N6265	SSD-205	228	543	RF
TA7994	2N6266	SSD-205	234	544	RF
TA7995	2N6267	SSD-205	240	545	RF
TA7995A	2N6269	SSD-205	246	546	RF
TA7996	D1201F	SSD-206	278	495	RECT
TA7999	40820	SSD-201	724	464	MOS/FET
TA8000	40821	SSD-201	724	464	MOS/FET
TA8001	40822	SSD-201	732	465	MOS/FET
TA8002	40823	SSD-201	732	465	MOS/FET
TA8004	2N6077	SSD-204	318	492	PWR
TA8005	2N6079	SSD-204	318	492	PWR
TA8007	2N6479	SSD-204	454	702	PWR
TA8007B	2N6480	SSD-204	454	702	PWR
TA8100	2N6481	SSD-204	454	702	PWR
TA8100B	2N6482	SSD-204	454	702	PWR
TA8104	40915	SSD-205	325	574	RF
TA8158	S3703SF	SSD206	194	522	SCR
TA8159	S3702SF	SSD-206	194	522	SCR
TA8160	D2103SF	SSD-206	298	522	RECT
TA8161	D2103S	SSD-206	298	522	RECT
TA8162	D2101S	SSD-206	298	522	RECT
TA8172	40970	SSD-205	359	656	RF
TA8197	T6400N	SSD-206	55	593	TRI
TA8198	T6410N	SSD-206	55	593	TRI
TA8199	T6420N	SSD-206	55	593	TRI
TA8201	2N6388	SSD-204	538	610	PWR
TA8202	2N6386	SSD-204	538	610	PWR
TA8210	2N6106	SSD-204	177	676	PWR
TA8211	2N6108	SSD-204	177	676	PWR
TA8212	2N6110	SSD-204	177	676	PWR
TA8231	2N6293	SSD-204	177	676	PWR
TA8232	2N6291	SSD-204	177	676	PWR
TA8236	40936	SSD-205	333	551	RF
TA8242	40841	SSD-201	739	489	MOS/FET
TA8247	40887	SSD-204	278	508	PWR
TA8248	40885	SSD-204	278	508	PWR
TA8249	40886	SSD-204	278	508	PWR
TA8323	2N6488	SSD-204	226	678	PWR
TA8324	2N6487	SSD-204	226	678	PWR
TA8325	2N6486	SSD-204	226	678	PWR
TA8326	2N6491	SSD-204	226	678	PWR
TA8327	2N6490	SSD-204	226	678	PWR
TA8328	2N6489	SSD-204	226	678	PWR
TA8330	2N6213	SSD-204	312	507	PWR
TA8331	2N6214	SSD-204	312	507	PWR
TA8340	41038	SSD-205	397	679	RF
TA8343	2N6478	SSD-204	83	680	PWR
TA8344	40894	SSD-205	309	548	RF
TA8345	40895	SSD-205	309	548	RF
TA8346	40896	SSD-205	309	548	RF
TA8347	40897	SSD-205	309	548	RF
TA8348	2N6385	SSD-204	532	609	PWR
TA8349	2N6383	SSD-204	532	609	PWR
TA8352	2N6372	SSD-204	170	675	PWR
TA8353	2N6373	SSD-204	170	675	PWR
TA8354	2N6374	SSD-204	170	675	PWR
TA8357	T2850B	SSD-206	79	540	TRI
TA8358	T2850D	SSD-206	79	540	TRI
TA8405	2N6477	SSD-204	83	680	PWR
TA8407	2N6268	SSD-205	246	546	RF
TA8411	D2406A	SSD-206	318	663	RECT
TA8412	D2406B	SSD-206	318	663	RECT
TA8413	D2406D	SSD-206	318	663	RECT
TA8414	D2406M	SSD-206	318	663	RECT
TA8415	D2412A	SSD-206	326	664	RECT
TA8416	D2412B	SSD-206	326	664	RECT
TA8417	D2412D	SSD-206	326	664	RECT
TA8418	D2412M	SSD-206	326	664	RECT
TA8419	D2520A	SSD-206	334	665	RECT
TA8420	D2520B	SSD-206	334	665	RECT
TA8421	D2520D	SSD-206	334	665	RECT
TA8422	D2520M	SSD-206	334	665	RECT
TA8425	R47M15	SSD-205	407	605	RF
TA8428	2N6254	SSD-204	102	524	PWR
TA8429	2N6253	SSD-204	102	524	PWR
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TA8433	2N6261	SSD-204	45	527	PWR
TA8434	2N6260	SSD-204	45	527	PWR
TA8435	2N6262	SSD-204	133	528	PWR
TA8436	2N6264	SSD-204	69	529	PWR
TA8437	2N6263	SSD-204	69	529	PWR
TA8439	40898	SSD-205	313	538	RF
TA8440	40899	SSD-205	313	538	RF
TA8442	2N6472	SSD-204	217	677	PWR
TA8443	2N6471	SSD-204	217	677	PWR
TA8444	2N6473	SSD-204	177	676	PWR
TA8445	2N6475	SSD-204	177	676	PWR
TA8485	2N6387	SSD-204	538	610	PWR
TA8486	2N6384	SSD-204	532	609	PWR
TA8493	40971	SSD-205	359	656	RF
TA8504	T2500B	SSD-206	49	615	TRI
TA8505	T2500D	SSD-206	49	615	TRI
TA8559	40954	SSD-205	346	579	RF
TA8561	40955	SSD-205	346	579	RF
TA8562	40967	SSD-205	355	596	RF
TA8563	40968	SSD-205	355	596	RF
TA8647	41025	SSD-205	383	641	RF
TA8648	41026	SSD-205	383	641	RF
TA8649	41027	SSD-205	390	640	RF
TA8650	41028	SSD-205	390	640	RF
TA8651A	HC2500	SSD-204	749	681	HYB
TA8656	2N3656	SSD-206	245	724	SCR
TA8657	2N3658	SSD-206	245	724	SCR
TA8709	2N6468	SSD-204	170	675	PWR
TA8710	2N6467	SSD-204	170	675	PWR
TA8712	R47M10	SSD-205	407	605	RF
TA8713	R47M13	SSD-205	407	605	RF
TA8719	41008	SSD-205	373	616	RF
TA8720	41009	SSD-205	373	616	RF
TA8721	41010	SSD-205	373	616	RF
TA8722	2N6476	SSD-204	177	676	PWR
TA8723	2N6474	SSD-204	177	676	PWR
TA8724	2N6469	SSD-204	217	677	PWR
TA8726	2N6470	SSD-204	217	677	PWR
TA8746	2N6393	SSD-205	270	628	RF
TA8747	2N6390	SSD-205	261	626	RF
TA8748	RCA2003	SSD-205	261	626	RF
TA8749	2N6391	SSD-205	265	627	RF
TA8750	RCA2005	SSD-205	265	627	RF
TA8751	2N6392	SSD-205	270	628	RF
TA8752	RCA2010	SSD-205	270	628	RF
TA8761	40637A	SSD-205	295	655	RF
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JAN2N1490	27	PWR	208
JAN2N1493	78	RF	247
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JAN2N3055	28	PWR	407
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JANTX2N3375	80	RF	341
JANTXV2N3375	80	RF	341
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JAN2N3553	80	RF	341
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JANTXV2N3553	80	RF	341
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JANTX2N3866	81	RF	398
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JANTX2N5109	82	RF	453
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1N443B	SSD-206	252	THC-500	5	RECT
1N444B	SSD-206	252	THC-500	5	RECT
1N445B	SSD-206	252	THC-500	5	RECT
1N536	SSD-206	255	THC-500	3	RECT
1N537	SSD-206	255	THC-500	3	RECT
1N538	SSD-206	255	THC-500	3	RECT
1N539	SSD-206	255	THC-500	3	RECT
1N540	SSD-206	255	THC-500	3	RECT
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1N1186A	SSD-206	291	THC-500	38	RECT
1N1187A	SSD-206	291	THC-500	38	RECT
1N1188A	SSD-206	291	THC-500	38	RECT
1N1189A	SSD-206	291	THC-500	38	RECT
1N1190A	SSD-206	291	THC-500	38	RECT
1N1195A	SSD-206	287	THC-500	6	RECT
1N1196A	SSD-206	287	THC-500	6	RECT
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1N2860A	SSD-206	265	THC-500	91	RECT
1N2861A	SSD-206	265	THC-500	91	RECT
1N2862A	SSD-206	265	THC-500	91	RECT
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1N3253	SSD-206	294	THC-500	41	RECT
1N3254	SSD-206	294	THC-500	41	RECT
1N3255	SSD-206	294	THC-500	41	RECT
1N3256	SSD-206	294	THC-500	41	RECT
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1N3880	SSD-206	323	THC-500	726	RECT
1N3881	SSD-206	323	THC-500	726	RECT
1N3882	SSD-206	323	THC-500	726	RECT
1N3883	SSD-206	323	THC-500	726	RECT
1N3889	SSD-206	331	THC-500	727	RECT
1N3890	SSD-206	331	THC-500	727	RECT
1N3891	SSD-206	331	THC-500	727	RECT
1N3892	SSD-206	331	THC-500	727	RECT
1N3893	SSD-206	331	THC-500	727	RECT
1N3899	SSD-206	339	THC-500	728	RECT
1N3900	SSD-206	339	THC-500	728	RECT
1N3901	SSD-206	339	THC-500	728	RECT
1N3902	SSD-206	339	THC-500	728	RECT
1N3903	SSD-206	339	THC-500	728	RECT
1N3909	SSD-206	342	THC-500	729	RECT
1N3910	SSD-206	342	THC-500	729	RECT
1N3911	SSD-206	342	THC-500	729	RECT
1N3912	SSD-206	342	THC-500	729	RECT
1N3913	SSD-206	342	THC-500	729	RECT
1N5211	SSD-206	270	THC-500	245	RECT
1N5216	SSD-206	270	THC-500	245	RECT
1N5217	SSD-206	270	THC-500	245	RECT
1N5218	SSD-206	270	THC-500	245	RECT
1N5391	SSD-206	273	THC-500	478	RECT
1N5392	SSD-206	273	THC-500	478	RECT
1N5393	SSD-206	273	THC-500	478	RECT
1N5394	SSD-206	273	THC-500	478	RECT
1N5395	SSD-206	273	THC-500	478	RECT
1N5396	SSD-206	273	THC-500	478	RECT
1N5397	SSD-206	273	THC-500	478	RECT
1N5398	SSD-206	273	THC-500	478	RECT
1N5399	SSD-206	273	THC-500	478	RECT
2N681	SSD-206	225	THC-500	96	SCR
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2N684	SSD-206	225	THC-500	96	SCR
2N685	SSD-206	225	THC-500	96	SCR
2N686	SSD-206	225	THC-500	96	SCR
2N687	SSD-206	225	THC-500	96	SCR
2N688	SSD-206	225	THC-500	96	SCR
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2N690	SSD-206	225	THC-500	96	SCR
2N697	SSD-204	493	PTD-187	16	PWR
2N699	SSD-204	495	PTD-187	22	PWR
2N918	SSD-204	692	RFT-700	83	RF
2N918	SSD-205	20	RFT-700	83	RF
2N1491	SSD-205	24	RFT-700	10	RF
2N1492	SSD-205	24	RFT-700	10	RF
2N1493	SSD-205	24	RFT-700	10	RF
2N1613	SSD-204	498	PTD-187	106	PWR
2N1711	SSD-204	503	PTD-187	26	PWR
2N1842A	SSD-206	234	THC-500	28	SCR
2N1843A	SSD-206	234	THC-500	28	SCR
2N1844A	SSD-206	234	THC-500	28	SCR
2N1845A	SSD-206	234	THC-500	28	SCR
2N1846A	SSD-206	234	THC-500	28	SCR
2N1847A	SSD-206	234	THC-500	28	SCR
2N1848A	SSD-206	234	THC-500	28	SCR
2N1849A	SSD-206	234	THC-500	28	SCR
2N1850A	SSD-206	234	THC-500	28	SCR
2N1893	SSD-204	507	PTD-187	34	PWR
2N2102	SSD-204	498	PTD-187	106	PWR
2N2102	SSD-207	34	–	–	PWR
2N2270	SSD-204	513	PTD-187	24	PWR
2N2405	SSD-204	507	PTD-187	34	PWR
2N2631	SSD-205	28	RFT-700	32	RF
2N2857	SSD-204	714	RFT-700	61	RF
2N2857	SSD-205	33	RFT-700	61	RF
2N2876	SSD-205	28	RFT-700	32	RF
2N2895	SSD-204	517	PTD-187	143	PWR
2N2896	SSD-204	517	PTD-187	143	PWR
2N2897	SSD-204	517	PTD-187	143	PWR
2N3053	SSD-204	404	PTD-187	432	PWR
2N3054	SSD-204	45	PTD-187	527	PWR
2N3054	SSD-207	34	–	–	PWR
2N3055	SSD-204	102	PTD-187	524	PWR
2N3118	SSD-205	37	RFT-700	42	RF
2N3119	SSD-205	41	RFT-700	44	RF
2N3228	SSD-206	144	THC-500	114	SCR
2N3229	SSD-205	45	RFT-700	50	RF
2N3262	SSD-205	48	RFT-700	56	RF
2N3263	SSD-204	475	PTD-187	54	PWR
2N3263	SSD-207	35	–	–	PWR
2N3264	SSD-204	475	PTD-187	54	PWR
2N3265	SSD-204	475	PTD-187	54	PWR
2N3266	SSD-204	475	PTD-187	54	PWR
2N3375	SSD-205	52	RFT-700	386	RF
2N3439	SSD-204	286	PTD-187	64	PWR
2N3440	SSD-204	286	PTD-187	64	PWR
2N3441	SSD-204	69	PTD-187	529	PWR
2N3442	SSD-204	133	PTD-187	528	PWR
2N3478	SSD-204	696	RFT-700	77	RF
2N3478	SSD-205	60	RFT-700	77	RF
2N3525	SSD-206	144	THC-500	114	SCR
2N3528	SSD-206	144	THC-500	114	SCR
2N3529	SSD-206	144	THC-500	114	SCR

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40349	SSD-204	26	PTD-187	88	PWR
40349V1	SSD-204	26	PTD-187	88	PWR
40349V2	SSD-204	26	PTD-187	88	PWR
40360	SSD-204	655	PTD-187	78	PWR
40361	SSD-204	655	PTD-187	78	PWR
40362	SSD-204	655	PTD-187	78	PWR
40363	SSD-204	655	PTD-187	78	PWR
40364	SSD-204	655	PTD-187	78	PWR
40366	SSD-204	397	PTD-187	215	PWR
40367	SSD-204	397	PTD-187	215	PWR
40368	SSD-204	397	PTD-187	215	PWR
40369	SSD-204	397	PTD-187	215	PWR
40372	SSD-204	45	PTD-187	527	PWR
40373	SSD-204	69	PTD-187	529	PWR
40374	SSD-204	304	PTD-187	128	PWR
40375	SSD-204	443	PTD-187	299	PWR
40385	SSD-204	397	PTD-187	215	PWR
40389	SSD-204	404	PTD-187	432	PWR
40390	SSD-204	286	PTD-187	64	PWR
40391	SSD-204	410	PTD-187	216	PWR
40392	SSD-204	404	PTD-187	432	PWR
40394	SSD-204	410	PTD-187	216	PWR
40406	SSD-204	661	PTD-187	219	PWR
40407	SSD-204	661	PTD-187	219	PWR
40408	SSD-204	661	PTD-187	219	PWR
40409	SSD-204	661	PTD-187	219	PWR
40410	SSD-204	661	PTD-187	219	PWR
40411	SSD-204	661	PTD-187	219	PWR
40412	SSD-204	393	PTD-187	211	PWR
40412V1	SSD-204	393	PTD-187	211	PWR
40412V2	SSD-204	393	PTD-187	211	PWR
40414	SSD-207	142	RFT-700	259	RF
40446	SSD-205	275	RFT-700	301	RF
40467A	SSD-201	681	MOS-160	324	MOS/FET
40468A	SSD-201	686	MOS-160	323	MOS/FET
40537	SSD-204	668	PTD-187	320	PWR
40538	SSD-204	668	PTD-187	320	PWR
40539	SSD-204	671	PTD-187	303	PWR
40542	SSD-204	675	PTD-187	304	PWR
40543	SSD-204	675	PTD-187	304	PWR
40544	SSD-204	671	PTD-187	303	PWR
40559A	SSD-201	686	MOS-160	323	MOS/FET
40577	SSD-207	148	RFT-700	297	RF
40578	SSD-207	155	RFT-700	298	RF
40581	SSD-205	275	RFT-700	301	RF
40582	SSD-205	275	RFT-700	301	RF
40594	SSD-204	681	PTD-187	358	PWR
40595	SSD-204	681	PTD-187	358	PWR
40600	SSD-201	712	MOS-160	333	MOS/FET
40601	SSD-201	712	MOS-160	333	MOS/FET
40602	SSD-201	712	MOS-160	333	MOS/FET
40603	SSD-201	720	MOS-160	334	MOS/FET
40604	SSD-201	720	MOS-160	334	MOS/FET
40605	SSD-207	161	RFT-700	389	RF
40606	SSD-207	168	RFT-700	600	RF
40608	SSD-204	728	RFT-700	356	RF
40608	SSD-205	291	RFT-700	356	RF
40611	SSD-204	681	PTD-187	358	PWR
40613	SSD-204	681	PTD-187	358	PWR
40616	SSD-204	681	PTD-187	358	PWR
40618	SSD-204	681	PTD-187	358	PWR
40621	SSD-204	681	PTD-187	358	PWR
40622	SSD-204	681	PTD-187	358	PWR
40624	SSD-204	681	PTD-187	358	PWR
40625	SSD-204	681	PTD-187	358	PWR
40627	SSD-204	681	PTD-187	358	PWR
40628	SSD-204	681	PTD-187	358	PWR
40629	SSD-204	681	PTD-187	358	PWR
40630	SSD-204	681	PTD-187	358	PWR
40631	SSD-204	681	PTD-187	358	PWR
40632	SSD-204	681	PTD-187	358	PWR
40633	SSD-204	681	PTD-187	358	PWR
40634	SSD-204	681	PTD-187	358	PWR
40635	SSD-204	681	PTD-187	358	PWR
40636	SSD-204	681	PTD-187	358	PWR
40637A	SSD-205	295	RFT-700	655	RF
40665	SSD-205	52	RFT-700	386	RF
40666	SSD-205	52	RFT-700	386	RF
40673	SSD-201	745	MOS-160	381	MOS/FET
40819	SSD-201	704	MOS-160	463	MOS/FET
40820	SSD-201	724	MOS-160	464	MOS/FET
40821	SSD-201	724	MOS-160	464	MOS/FET
40822	SSD-201	732	MOS-160	465	MOS/FET
40823	SSD-201	732	MOS-160	465	MOS/FET
40829	SSD-204	170	PTD-187	675	PWR
40830	SSD-204	170	PTD-187	675	PWR
40831	SSD-204	170	PTD-187	675	PWR
40836	SSD-205	298	RFT-700	497	RF
40837	SSD-205	298	RFT-700	497	RF
40841	SSD-201	739	MOS-160	489	MOS/FET
40850	SSD-204	368	PTD-187	498	PWR
40851	SSD-204	368	PTD-187	498	PWR
40852	SSD-204	368	PTD-187	498	PWR
40853	SSD-204	368	PTD-187	498	PWR
40854	SSD-204	368	PTD-187	498	PWR
40871	SSD-204	685	PTD-187	699	PWR
40872	SSD-204	685	PTD-187	699	PWR
40873	SSD-204	685	PTD-187	699	PWR
40874	SSD-204	685	PTD-187	699	PWR
40875	SSD-204	685	PTD-187	699	PWR
40876	SSD-204	685	PTD-187	699	PWR
40885	SSD-204	278	PTD-187	508	PWR
40886	SSD-204	278	PTD-187	508	PWR
40887	SSD-204	278	PTD-187	508	PWR
40893	SSD-205	304	RFT-700	514	RF
40894	SSD-204	706	RFT-700	548	RF
40894	SSD-205	309	RFT-700	548	RF
40895	SSD-204	706	RFT-700	548	RF
40895	SSD-205	309	RFT-700	548	RF
40896	SSD-204	706	RFT-700	548	RF
40896	SSD-205	309	RFT-700	548	RF
40897	SSD-204	706	RFT-700	548	RF
40897	SSD-205	309	RFT-700	548	RF
40898	SSD-205	313	RFT-700	538	RF
40899	SSD-205	313	RFT-700	538	RF
40909	SSD-205	321	RFT-700	547	RF
40910	SSD-204	45	PTD-187	527	PWR
40911	SSD-204	45	PTD-187	527	PWR
40912	SSD-204	69	PTD-187	529	PWR
40913	SSD-204	69	PTD-187	529	PWR
40915	SSD-204	710	RFT-700	574	RF
40915	SSD-205	325	RFT-700	574	RF
40934	SSD-205	329	RFT-700	550	RF
40936	SSD-205	333	RFT-700	551	RF
40940	SSD-205	337	RFT-700	553	RF
40941	SSD-205	342	RFT-700	554	RF
40953	SSD-205	346	RFT-700	579	RF
40954	SSD-205	346	RFT-700	579	RF
40955	SSD-205	346	RFT-700	579	RF
40964	SSD-205	351	RFT-700	581	RF
40965	SSD-205	351	RFT-700	581	RF
40967	SSD-205	355	RFT-700	596	RF
40968	SSD-205	355	RFT-700	596	RF
40970	SSD-205	359	RFT-700	656	RF
40971	SSD-205	359	RFT-700	656	RF
40972	SSD-205	365	RFT-700	597	RF
40973	SSD-205	365	RFT-700	597	RF
40974	SSD-205	365	RFT-700	597	RF
40975	SSD-205	369	RFT-700	606	RF
40976	SSD-205	369	RFT-700	606	RF
40977	SSD-205	369	RFT-700	606	RF
41008	SSD-205	373	RFT-700	616	RF
41008A	SSD-205	373	RFT-700	616	RF
41009	SSD-205	373	RFT-700	616	RF
41009A	SSD-205	373	RFT-700	616	RF
41010	SSD-205	373	RFT-700	616	RF
41024	SSD-205	379	RFT-700	658	RF
41025	SSD-205	383	RFT-700	641	RF
41026	SSD-205	383	RFT-700	641	RF
41027	SSD-205	390	RFT-700	640	RF
41028	SSD-205	390	RFT-700	640	RF
41038	SSD-205	397	RFT-700	679	RF
41508	SSD-204	157	PTD-187	622	PWR
45190	SSD-204	273	PTD-187	559	PWR
45191	SSD-204	273	PTD-187	559	PWR
45192	SSD-204	273	PTD-187	559	PWR
45193	SSD-204	273	PTD-187	559	PWR
45194	SSD-204	273	PTD-187	559	PWR
45195	SSD-204	273	PTD-187	559	PWR

BD183	SSD-204	115	—	700	PWR
BD239	SSD-204	193	—	669	PWR
BD239A	SSD-204	193	—	669	PWR
BD239B	SSD-204	193	—	669	PWR
BD239C	SSD-204	193	—	669	PWR
BD240	SSD-204	197	—	670	PWR
BD240A	SSD-204	197	—	670	PWR
BD240B	SSD-204	197	—	670	PWR
BD240C	SSD-204	197	—	670	PWR
BD241	SSD-204	201	—	671	PWR
BD241A	SSD-204	201	—	671	PWR
BD241B	SSD-204	201	—	671	PWR
BD241C	SSD-204	201	—	671	PWR
BD242	SSD-204	205	—	672	PWR
BD242A	SSD-204	205	—	672	PWR
BD242B	SSD-204	205	—	672	PWR
BD242C	SSD-204	205	—	672	PWR
BD243	SSD-204	209	—	673	PWR
BD243A	SSD-204	209	—	673	PWR
BD243B	SSD-204	209	—	673	PWR
BD243C	SSD-204	209	—	673	PWR
BD244	SSD-204	213	—	674	PWR
BD244A	SSD-204	213	—	674	PWR
BD244B	SSD-204	213	—	674	PWR
BD244C	SSD-204	213	—	674	PWR
BD277	SSD-204	189	—	667	PWR
BD278	SSD-204	129	—	668	PWR
BDX33	SSD-204	545	—	693	PWR
BDX33A	SSD-204	545	—	693	PWR
BDX33B	SSD-204	545	—	693	PWR
BDX33C	SSD-204	545	—	693	PWR
BDX34	SSD-204	551	—	694	PWR
BDX34A	SSD-204	551	—	694	PWR
BDX34B	SSD-204	551	—	694	PWR
BDX34C	SSD-204	551	—	694	PWR
BFT19	SSD-204	298	—	683	PWR
BFT19A	SSD-204	298	—	683	PWR
BFT19B	SSD-204	298	—	683	PWR
BU106	SSD-204	363	—	716	PWR
CA108AS	SSD-201	105	CDL-820	621	LIC
CA108AT	SSD-201	105	CDL-820	621	LIC
CA108S	SSD-201	105	CDL-820	621	LIC
CA108T	SSD-201	105	CDL-820	621	LIC
CA208AS	SSD-201	105	CDL-820	621	LIC
CA208AT	SSD-201	105	CDL-820	621	LIC
CA208S	SSD-201	105	CDL-820	621	LIC
CA208T	SSD-201	105	CDL-820	621	LIC
CA308AS	SSD-201	105	CDL-820	621	LIC
CA308AT	SSD-201	105	CDL-820	621	LIC
CA308H	SSD-201	590	CDL-820	516	LIC
CA308S	SSD-201	105	CDL-820	621	LIC
CA308T	SSD-201	105	CDL-820	621	LIC
CA741/1-4	SSD-207	188	—	718	LIC
CA741CH	SSD-201	590	CDL-820	516	LIC
CA741CS	SSD-201	74	CDL-820	531	LIC
CA741CT	SSD-201	74	CDL-820	531	LIC
CA741L	SSD-201	605	CDL-820	515	LIC
CA741S	SSD-201	74	CDL-820	531	LIC
CA741T	SSD-201	74	CDL-820	531	LIC
CA747/1-4	SSD-207	188	—	718	LIC
CA747CE	SSD-201	74	CDL-820	531	LIC
CA747CF	SSD-201	74	CDL-820	531	LIC
CA747CH	SSD-201	590	CDL-820	516	LIC
CA747CT	SSD-201	74	CDL-820	531	LIC
CA747E	SSD-201	74	CDL-820	531	LIC
CA747F	SSD-201	74	CDL-820	531	LIC
CA747T	SSD-201	74	CDL-820	531	LIC
CA748/1-4	SSD-207	188	—	718	LIC
CA748CH	SSD-201	590	CDL-820	516	LIC
CA748CS	SSD-201	74	CDL-820	531	LIC
CA748CT	SSD-201	74	CDL-820	531	LIC
CA748S	SSD-201	74	CDL-820	531	LIC
CA748T	SSD-201	74	CDL-820	531	LIC
CA1398E	SSD-201	573	CDL-820	686	LIC
CA1458S	SSD-201	74	CDL-820	531	LIC
CA1458T	SSD-201	74	CDL-820	531	LIC
CA1541D	SSD-201	395	CDL-820	536	LIC
CA1558T	SSD-201	74	CDL-820	531	LIC
CA2111AE	SSD-201	520	CDL-820	612	LIC
CA2111AQ	SSD-201	520	CDL-820	612	LIC
CA3000	SSD-201	288	CDL-820	121	LIC
CA3000/1-4	SSD-207	196	—	705	LIC
CA3000H	SSD-201	590	CDL-820	516	LIC
CA3001	SSD-201	294	CDL-820	122	LIC
CA3001/1-4	SSD-207	203	—	714	LIC
CA3001H	SSD-201	590	CDL-820	516	LIC
CA3002	SSD-201	256	CDL-820	123	LIC
CA3002/1-4	SSD-207	210	—	713	LIC
CA3002H	SSD-201	590	CDL-820	516	LIC
CA3004	SSD-201	300	CDL-820	124	LIC
CA3004/1-4	SSD-207	216	—	712	LIC
CA3005	SSD-201	306	CDL-820	125	LIC
CA3005H	SSD-201	590	CDL-820	516	LIC
CA3006	SSD-201	306	CDL-820	125	LIC
CA3007	SSD-201	313	CDL-820	126	LIC
CA3008	SSD-201	80	CDL-820	316	LIC
CA3008A	SSD-201	89	CDL-820	310	LIC
CA3010	SSD-201	80	CDL-820	316	LIC
CA3010A	SSD-201	89	CDL-820	310	LIC
CA3011	SSD-201	262	CDL-820	128	LIC
CA3012	SSD-201	262	CDL-820	128	LIC
CA3012H	SSD-201	590	CDL-820	516	LIC
CA3013	SSD-201	471	CDL-820	129	LIC
CA3014	SSD-201	471	CDL-820	129	LIC
CA3015	SSD-201	80	CDL-820	316	LIC
CA3015A	SSD-201	89	CDL-820	310	LIC
CA3015A/1-4	SSD-207	222	—	715	LIC
CA3015H	SSD-201	590	CDL-820	516	LIC
CA3015L	SSD-201	605	CDL-820	515	LIC
CA3016	SSD-201	80	CDL-820	316	LIC
CA3016A	SSD-201	89	CDL-820	310	LIC
CA3018	SSD-201	160	CDL-820	338	LIC
CA3018A	SSD-201	160	CDL-820	338	LIC
CA3018H	SSD-201	590	CDL-820	516	LIC
CA3018L	SSD-201	605	CDL-820	515	LIC
CA3019	SSD-201	118	CDL-820	236	LIC
CA3019/1-4	SSD-207	229	—	722	LIC
CA3019H	SSD-201	590	CDL-820	516	LIC
CA3020	SSD-201	268	CDL-820	339	LIC
CA3020A	SSD-201	268	CDL-820	339	LIC
CA3020H	SSD-201	590	CDL-820	516	LIC
CA3021	SSD-201	276	CDL-820	243	LIC
CA3022	SSD-201	276	CDL-820	243	LIC
CA3023	SSD-201	276	CDL-820	243	LIC
CA3023H	SSD-201	590	CDL-820	516	LIC
CA3026	SSD-201	226	CDL-820	388	LIC
CA3026/1-4	SSD-207	235	—	706	LIC
CA3026H	SSD-201	590	CDL-820	516	LIC
CA3028A	SSD-201	318	CDL-820	382	LIC
CA3028AF	SSD-201	318	CDL-820	382	LIC
CA3028AH	SSD-201	590	CDL-820	516	LIC
CA3028AL	SSD-201	605	CDL-820	515	LIC
CA3028AS	SSD-201	318	CDL-820	382	LIC
CA3028B	SSD-201	318	CDL-820	382	LIC
CA3028B/1-4	SSD-207	243	—	711	LIC
CA3028BF	SSD-201	318	CDL-820	382	LIC
CA3028BS	SSD-201	318	CDL-820	382	LIC
CA3029	SSD-201	80	CDL-820	316	LIC
CA3029A	SSD-201	89	CDL-820	310	LIC
CA3030	SSD-201	80	CDL-820	316	LIC
CA3030A	SSD-201	89	CDL-820	310	LIC
CA3033	SSD-201	61	CDL-820	360	LIC
CA3033A	SSD-201	61	CDL-820	360	LIC
CA3033H	SSD-201	590	CDL-820	516	LIC
CA3035	SSD-201	243	CDL-820	274	LIC
CA3035H	SSD-201	590	CDL-820	516	LIC
CA3035V1	SSD-201	243	CDL-820	274	LIC
CA3036	SSD-201	158	CDL-820	275	LIC
CA3037	SSD-201	80	CDL-820	316	LIC
CA3037A	SSD-201	89	CDL-820	310	LIC
CA3038	SSD-201	80	CDL-820	316	LIC
CA3038A	SSD-201	89	CDL-820	310	LIC
CA3039	SSD-201	122	CDL-820	343	LIC
CA3039/1-4	SSD-207	250	—	704	LIC

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D2406M	SSD-206	318	THC-500	663	RECT
D2412A	SSD-206	326	THC-500	664	RECT
D2412B	SSD-206	326	THC-500	664	RECT
D2412C	SSD-206	326	THC-500	664	RECT
D2412D	SSD-206	326	THC-500	664	RECT
D2412F	SSD-206	326	THC-500	664	RECT
D2412M	SSD-206	326	THC-500	664	RECT
D2520A	SSD-206	334	THC-500	665	RECT
D2520B	SSD-206	334	THC-500	665	RECT
D2520C	SSD-206	334	THC-500	665	RECT
D2520D	SSD-206	334	THC-500	665	RECT
D2520F	SSD-206	334	THC-500	665	RECT
D2520M	SSD-206	334	THC-500	665	RECT
D2540A	SSD-206	345	THC-500	580	RECT
D2540B	SSD-206	345	THC-500	580	RECT
D2540D	SSD-206	345	THC-500	580	RECT
D2540F	SSD-206	345	THC-500	580	RECT
D2540M	SSD-206	345	THC-500	580	RECT
D2601A	SSD-206	308	THC-500	723	RECT
D2601B	SSD-206	308	THC-500	723	RECT
D2601D	SSD-206	308	THC-500	723	RECT
D2601F	SSD-206	308	THC-500	723	RECT
D2601M	SSD-206	308	THC-500	723	RECT
D2601N	SSD-206	308	THC-500	723	RECT
D2600EF	SSD-206	303	THC-500	354	RECT
D2601DF	SSD-206	303	THC-500	354	RECT
D2601EF	SSD-206	303	THC-500	354	RECT
D3202Y	SSD-206	350	THC-500	577	DIAC
D3202U	SSD-206	350	THC-500	577	DIAC
HC2000H	SSD-204	744	–	566	HYB
HC2500	SSD-204	749	–	681	HYB
HR2N2857	SSD-207	83	–	–	RF
HR2N3866	SSD-207	85	–	–	RF
HR2N5090	SSD-207	87	–	–	RF
HR2N5470	SSD-207	89	–	–	RF
HR2N5916	SSD-207	91	–	–	RF
HR2N5918	SSD-207	93	–	–	RF
HR2N5919A	SSD-207	95	–	–	RF
HR2N5920	SSD-207	97	–	–	RF
HR2N5921	SSD-207	99	–	–	RF
HR2N6105	SSD-207	101	–	–	RF
HR2N6265	SSD-207	103	–	–	RF
HR2N6266	SSD-207	105	–	–	RF
HR2N6267	SSD-207	107	–	–	RF
HR2N6268	SSD-207	109	–	–	RF
HR2N6269	SSD-207	109	–	–	RF
HR2N6390	SSD-207	111	–	–	RF
HR2N6391	SSD-207	113	–	–	RF
HR2N6392	SSD-207	115	–	–	RF
HR2N6393	SSD-207	115	–	–	RF
HR2003	SSD-207	111	–	–	RF
HR2005	SSD-207	113	–	–	RF
HR2010	SSD-207	115	–	–	RF
HR3001	SSD-207	117	–	–	RF
HR3003	SSD-207	117	–	–	RF
HR3005	SSD-207	117	–	–	RF
JAN2N918	SSD-207	78	–	–	RF
JAN2N1482	SSD-207	26	–	–	PWR
JAN2N1486	SSD-207	26	–	–	PWR
JAN2N1490	SSD-207	27	–	–	PWR
JAN2N1493	SSD-207	78	–	–	RF
JAN2N2016	SSD-207	27	–	–	PWR
JAN2N2857	SSD-207	79	–	–	RF
JAN2N3055	SSD-207	28	–	–	PWR
JAN2N3375	SSD-207	80	–	–	RF
JAN2N3439	SSD-207	28	–	–	PWR
JAN2N3441	SSD-207	29	–	–	PWR
JAN2N3442	SSD-207	29	–	–	PWR
JAN2N3553	SSD-207	80	–	–	RF
JAN2N3585	SSD-207	30	–	–	PWR
JAN2N3772	SSD-207	30	–	–	PWR
JAN2N3866	SSD-207	81	–	–	RF
JAN2N4440	SSD-207	80	–	–	RF
JAN2N5038	SSD-207	31	–	–	PWR
JAN2N5071	SSD-207	81	–	–	RF
JAN2N5109	SSD-207	82	–	–	RF
JAN2N5840	SSD-207	32	–	–	PWR
JAN2N5918	SSD-207	82	–	–	RF
JAN2N6213	SSD-207	33	–	–	PWR
JANTX2N1486	SSD-207	26	–	–	PWR
JANTX2N2857	SSD-207	79	–	–	RF
JANTX2N3055	SSD-207	28	–	–	PWR
JANTX2N3375	SSD-207	80	–	–	RF
JANTX2N3439	SSD-207	28	–	–	PWR
JANTX2N3441	SSD-207	29	–	–	PWR
JANTX2N3553	SSD-207	80	–	–	RF
JANTX2N3585	SSD-207	30	–	–	PWR
JANTX2N4440	SSD-207	80	–	–	RF
JANTX2N5038	SSD-207	31	–	–	PWR
JANTX2N5071	SSD-207	81	–	–	RF
JANTX2N5109	SSD-207	82	–	–	RF
JANTX2N5416	SSD-207	31	–	–	PWR
JANTX2N5672	SSD-207	32	–	–	PWR
JANTX2N5840	SSD-207	32	–	–	PWR
JANTX2N6213	SSD-207	33	–	–	PWR
JANTXV2N3375	SSD-207	80	–	–	RF
JANTXV2N3553	SSD-207	80	–	–	RF
JANTXV2N4440	SSD-207	80	–	–	RF
R47M10	SSD-205	407	RFT-700	605	RF
R47M13	SSD-205	407	RFT-700	605	RF
R47M15	SSD-205	407	RFT-700	605	RF
RCA1A01	SSD-204	636	PTD-187	651	PWR
RCA1A02	SSD-204	636	PTD-187	651	PWR
RCA1A03	SSD-204	636	PTD-187	651	PWR
RCA1A04	SSD-204	636	PTD-187	651	PWR
RCA1A05	SSD-204	636	PTD-187	651	PWR
RCA1A06	SSD-204	636	PTD-187	651	PWR
RCA1A07	SSD-204	636	PTD-187	651	PWR
RCA1A08	SSD-204	636	PTD-187	651	PWR
RCA1A09	SSD-204	636	PTD-187	651	PWR
RCA1A10	SSD-204	636	PTD-187	651	PWR
RCA1A11	SSD-204	636	PTD-187	651	PWR
RCA1A15	SSD-204	636	PTD-187	651	PWR
RCA1A16	SSD-204	636	PTD-187	651	PWR
RCA1A17	SSD-204	636	PTD-187	651	PWR
RCA1A18	SSD-204	636	PTD-187	651	PWR
RCA1A19	SSD-204	636	PTD-187	651	PWR
RCA1B01	SSD-204	600	PTD-187	647	PWR
RCA1B04	SSD-204	618	PTD-187	649	PWR
RCA1B05	SSD-204	627	PTD-187	650	PWR
RCA1B06	SSD-204	609	PTD-187	648	PWR
RCA1C03	SSD-204	647	PTD-187	652	PWR
RCA1C04	SSD-204	647	PTD-187	652	PWR
RCA1C05	SSD-204	575	PTD-187	644	PWR
RCA1C06	SSD-204	575	PTD-187	644	PWR
RCA1C07	SSD-204	592	PTD-187	646	PWR
RCA1C08	SSD-204	592	PTD-187	646	PWR
RCA1C09	SSD-204	583	PTD-187	645	PWR
RCA1C10	SSD-204	558	PTD-187	642	PWR
RCA1C11	SSD-204	558	PTD-187	642	PWR
RCA1C12	SSD-204	647	PTD-187	652	PWR
RCA1C13	SSD-204	647	PTD-187	652	PWR
RCA1C14	SSD-204	566	PTD-187	643	PWR
RCA1E02	SSD-204	651	PTD-187	653	PWR
RCA1E03	SSD-204	651	PTD-187	653	PWR
RCA29	SSD-204	232	PTD-187	583	PWR
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RCA30	SSD-204	237	PTD-187	584	PWR
RCA30A	SSD-204	237	PTD-187	584	PWR
RCA30B	SSD-204	237	PTD-187	584	PWR
RCA30C	SSD-204	237	PTD-187	584	PWR
RCA31	SSD-204	242	PTD-187	585	PWR
RCA31A	SSD-204	242	PTD-187	585	PWR
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RCA520	SSD-204	270	PTD-187	558	PWR
RCA521	SSD-204	270	PTD-187	558	PWR
RCA1000	SSD-204	524	PTD-187	594	PWR
RCA1001	SSD-204	524	PTD-187	594	PWR
RCA2003	SSD-205	261	RFT-700	626	RF
RCA2005	SSD-205	265	RFT-700	627	RF
RCA2010	SSD-205	270	RFT-700	628	RF
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RCA3003	SSD-205	401	RFT-700	657	RF
RCA3005	SSD-205	401	RFT-700	657	RF
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RCA3055	SSD-204	53	PTD-187	618	PWR
RCA3441	SSD-204	77	PTD-187	666	PWR
RCA6263	SSD-204	77	PTD-187	666	PWR
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S2620M	SSD-206	156	THC-500	496	SCR
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S3704A	SSD-206	180	THC-500	690	SCR
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S3800M	SSD-206	199	THC-500	639	ITR
S3800MF	SSD-206	199	THC-500	639	ITR
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